PB86-116621

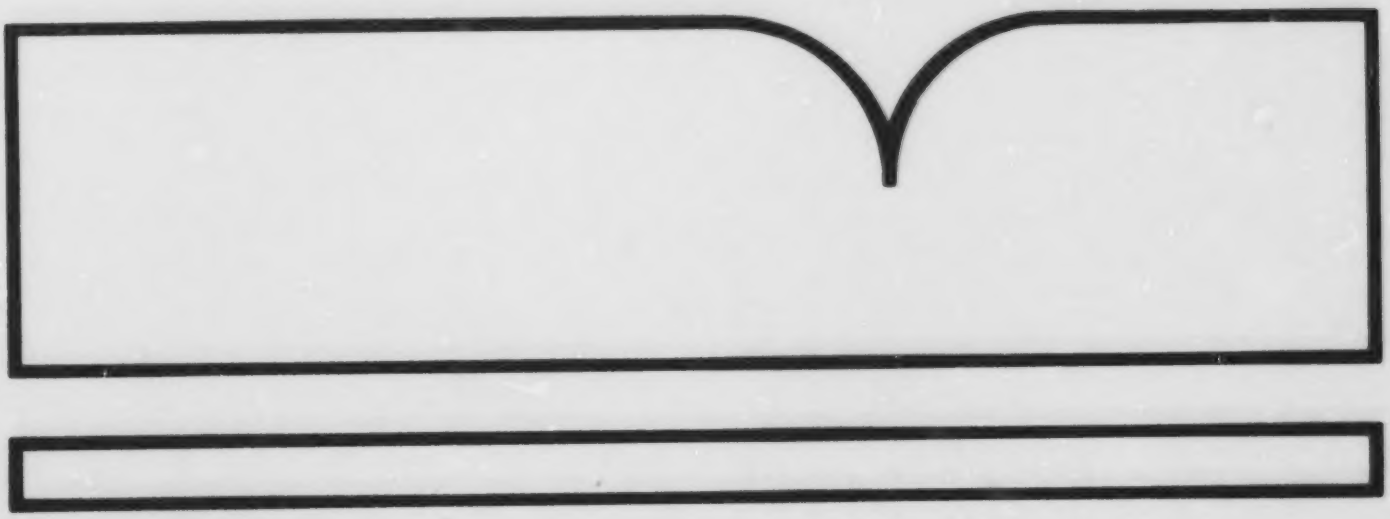
Soil Physicochemical Parameters Affecting Metal Availability in Sludge-Amended Soils

Louisiana State Univ., Baton Rouge

Prepared for

Environmental Protection Agency
Cincinnati, OH

Oct 85



U.S. Department of Commerce
National Technical Information Service
NTIS

PB86-116621

EPA/600/2-85/123
October 1985

SOIL PHYSICOCHEMICAL PARAMETERS AFFECTING METAL AVAILABILITY IN SLUDGE-AMENDED SOILS

by

Robert P. Gambrell, William H. Patrick, Jr., Susan L. Landes, and
and C. N. Reddy
Louisiana State University
Baton Rouge, Louisiana 70803

Grant No. R805789

Project Officer

James A. Ryan
Wastewater Research Division
Water Engineering Research Laboratory
Cincinnati, Ohio 45268

WATER ENGINEERING RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA/600/2-85/123	2.
3. RECIPIENT'S ACCESSION NO. PB86 116217/AS	
4. TITLE AND SUBTITLE Soil Physicochemical Parameters Affecting Metal Availability in Sludge-Amended Soils	5. REPORT DATE October 1985
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) R. P. Gambrell, W. H. Patrick, Jr., S. L. Landes, and C. N. Reddy	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Center for Wetland Resources Louisiana State University Baton Rouge, Louisiana 70803	10. PROGRAM ELEMENT NO. CAZB1B
	11. CONTRACT/GRANT NO. R-805789
12. SPONSORING AGENCY NAME AND ADDRESS Water Engineering Research Laboratory, Cin., OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268	13. TYPE OF REPORT AND PERIOD COVERED Final - 1978-1982
	14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES
Project Officer: James A. Ryan (513) 569-7653

16. ABSTRACT A series of laboratory studies was conducted to determine the effects of soil pH and redox potential on levels of trace metals (Cu, Zn, Cd, Pb, Cr, Ni, and As) in selected chemical forms and their availability to plants.

This research demonstrates the important effects of soil redox potential conditions in regulating the chemical mobility and plant availability of Zn and Cd, two key contaminants in sludge materials that may be applied to soils. Where alternatives exist for disposal of contaminaed sludge, wet or poorly oxidized soils would be more effective in immobilizing Zn and Cd, and application to these soils would result in less accumulation of these metals in most crops or plants in uncultivated habitats.

Unlike results for Cd and Zn, oxidation status had little, if any, effect on plant levels of Cr, Ni, and As. Predominant chemical forms in the sludge-amended soils and oxidation effects on levels in these chemical forms are discussed in the report.

Chemical availability and plant uptake studies under controlled pH and redox potential conditions indicated various organic phases predominant in retaining Cu under reducing conditions. Results with rice were mixed, but increasing oxidation conditions tended to increase Cu in corn.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS (This Report) UNCLASSIFIED	21. NO. OF PAGES 113
	20. SECURITY CLASS (This page) UNCLASSIFIED	22. PRICE $16.95

EPA Form 2220-1 (9-73)

DISCLAIMER NOTICE

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FOREWORD

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water systems. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. The Clean Water Act, the Safe Drinking Water Act, and the Toxics Substances Control Act are three of the major congressional laws that provide the framework for restoring and maintaining the integrity of our Nation's water, for preserving and enhancing the water we drink, and for protecting the environment from toxic substances. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Water Engineering Research Laboratory is that component of EPA's Research and Development program concerned with preventing, treating, and managing municipal and industrial wastewater discharges; establishing practices to control and remove contaminants from drinking water and to prevent its deterioration during storage and distribution; and assessing the nature and controllability of releases of toxic substances to the air, water, and land from manufacturing processes and subsequent product uses. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

This report summarizes the results of a series of experiments designed to evaluate the impact of soil oxidation status and pH on the solubility and plant availability of trace metals added to soil via land application of municipal sewage sludge. The results make a significant contribution to our understanding ofd the fate of metals in the soil environment.

Francis T. Mayo, Director
Water Engineering Research Laboratory

ABSTRACT

A series of laboratory studies were conducted examining the effects of soil pH and redox potential (oxidation-reduction status) conditions on the levels of trace and toxic metals in selected chemical forms. Studies were also conducted to see how plant availability of the metals was affected by soil oxidation-reduction conditions. The elements studied included Cu, Zn, Cd, Pb, Cr, Ni, and As.

Chemical availability and plant uptake studies under controlled pH and redox potential conditions indicated various organic phases predominate in retaining Cu under reducing conditions. As redox potential is increased, however, a very marked transformation occurs such that potentially available Cu becomes strongly associated with the reducible (hydrous iron oxide) phase under well-oxidized conditions. Soluble, exchangeable, and chelate-extractable Cu also increased with increasing redox potential. Results with rice were mixed, but increasing oxidation conditions tended to increase Cu in corn.

Dissolved and exchangeable Zn increased with decreasing pH and increased to a lesser degree with increasing redox potential. A very large increase in plant Zn levels occurred with increasing redox potential.

Compared with most other trace and toxic metals studied, a much larger proportion of the total Cd extracted was recovered in the most readily available chemical forms (dissolved and exchangeable). Cadmium appears less strongly associated (immobilized) with high-molecular weight organics and is weakly bound to hydrous iron oxides. This contributes to a situation in which Cd is readily accumulated by plants grown in Cd-contaminated soils. In most of the experimental combinations of sludge-soil mixtures and pH used in the laboratory microcosm, plant Cd concentrations increased greatly as the redox potential increased.

Except for exchangeable lead being greater at pH 5.0 compared to higher pH levels, changing physicochemical conditions had little effect on levels of Pb in other chemical forms.

Unlike results for Cd and Zn, oxidation status had little, if any, effect on plant levels of Cr, Ni, and As. Predominant chemical forms in the sludge-amended soils and oxidation effects on levels in these chemical forms are discussed in the report.

This research demonstrates the important effects of soil redox potential conditions in regulating the chemical mobility and plant availability of Zn and Cd, two key contaminants in sludge materials that may be applied to soils. Where alternatives exist for disposal of contaminated sludge, wet or poorly oxidized soils would be more effective in immobilizing Zn and Cd, and application to these soils would result in less accumulation of these metals in most crops or plants in uncultivated habitats.

This report was submitted in fulfillment of Contract No. R805789 by Louisiana State University under the sponsorship of the U.S. Environmental Protection Agency.

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SECTION 1

INTRODUCTION

BACKGROUND

Disposal of sewage and similar waste by land application has been practiced on a small scale in Europe and this country for 100 years and longer. But only during the last decade has the application of municipal sludge to agricultural soils gained widespread research attention and considerable acceptance as a method of waste disposal and resource utilization.

The Federal Water Pollution Control Act of 1972 (PL 92-500) has stimulated increasing interest in the use of terrestrial ecosystems to achieve water quality standards. Section 201(b) requires that technology development consider advanced waste treatment techniques and include the reclaiming and recycling of water and the confined disposal of pollutants so they will not migrate or cause water or other environmental pollution. The application of municipal sewage sludge to soil-crop systems may be the most environmentally and economically feasible method of meeting these requirements in many instances. Benefits of land application of municipal sludge include: 1) reducing the pollution load of river and coastal waters that have traditionally received sewage wastes, 2) recycling water and nutrients through crops to recover these valuable resources, 3) more rapid inactivation or destruction of potentially serious microbial pathogenic organisms than some conventional wastewater treatment methods (Braids, Ardakani, and Molina, 1970), and 4) possible improvement of marginal soils for developing land for parks and other urban uses (Peterson, McCalla, and Smith, 1971).

The most serious limitation of applying municipal sludge to agricultural soils concerns the fate of pathogens and toxic substances that may be associated with municipal wastes. Such materials include bacterial and viral infectious agents, synthetic organic toxins such as pesticides and PCB's, and toxic heavy metals. Toxic heavy metals in sludge-amended soils and the crops grown on these soils have been studied extensively because of the tendency for these metals to accumulate in soils and to be assimilated by plants. Crop uptake of toxic metals may increase their dietary intake by livestock and humans who consume these plants as a food source.

Problems may be manifested quickly or only after long-term waste applications. For example, the heavy metal content of crops grown on sludge-treated soils may be increased to unsafe levels soon after sludge

application is initiated. Or, continued sludge application may eventually result in an accumulation of toxic heavy metals in soils and subsequently crops that may either adversely affect human health or ruin the soil for food production after many years. As will be documented and discussed more fully in the review of literature, many studies demonstrate that trace and toxic metals move readily into above-ground plant tissue, whereas other investigations have shown these metals to be relatively unavailable to crop plants. This range in plant availability demonstrates the variability of factors regulating the mobilization of toxic metals.

Extensive agricultural research has shown that a number of interacting physical, chemical, and biological factors affect the availability of nutrients and toxins in soil-plant systems. For example, the kind and amount of clay minerals and soil organic matter and the presence of additional chemically reactive or adsorptive soil components such as sulfides and hydrous oxides play an important role in regulating bioavailability. Plant species and management of soils, crops, and waste applications are also important factors. Fortunately, most soils -- even those which are highly contaminated -- have a large capacity to immobilize toxic metals so that only a small proportion of the total metals applied is available to organisms. But all of the metals applied with sludge applications must be considered potentially available for plant uptake. Because of the probable long-term accumulation of potentially available toxic metals in sludge-amended soils and the dynamic nature of soil-plant systems, it is imperative that we understand the factors and processes affecting their availability.

Soil pH and oxidation-reduction conditions are two physicochemical parameters that affect metal mobilization and immobilization processes. Considerable research has been conducted on the effects of soil pH on the chemical availability and plant uptake of trace and toxic metals by crop plants grown on soils treated with municipal sludge. As will be discussed in the literature review, these studies have markedly demonstrated that an increase in soil acidity usually enhances plant availability of trace and toxic metals. In contrast, very little is known of the effects of oxidation-reduction conditions on toxic metal availability. Soil oxidation-reduction conditions are probably as important as soil pH in regulating the availability of metals. Most soils currently receiving municipal sludge are upland soils classified as moderately well- to well-drained; such soils are generally considered aerobic or oxidized.

Municipal sludge may also be applied to wetland soils characterized by poor internal drainage or water saturation for much of the time. These soils are likely to be anaerobic and chemically reduced. Because of increased restrictions on dumping pollutants in coastal waters and the ever-present shortage of conveniently located land suitable for disposal, it is probable that pressures will increase to utilize poorly drained agricultural and wetland soils for waste disposal.

In addition to the range in general soil oxidation types, it is likely that the addition of large quantities of sludge (frequently as a water

slurry) containing high levels of organic matter may contribute to intermittent, strongly reduced conditions in all or part of the rhizosphere of an upland soil that is normally considered well drained and oxidized. Thus a wide range of oxidation-reduction conditions may be encountered in sludge-amended soils, resulting in varying degrees of plant availability of toxic metals applied with sludge.

OBJECTIVES

The primary objective of this study was to determine the effects of soil pH and especially oxidation-reduction (redox) conditions on the soil chemical form and plant availability of trace and toxic metals in agricultural soils receiving municipal sludge applications. The elements studied were Cu, Zn, Cd, Pb, Cr, Ni, As, Fe, Mn, Ca, Mg, Mo, Si, P, and Al.

In chemical availability studies, sludge-amended soil-water suspensions were incubated under conditions of controlled pH and redox potential over the range of these parameters expected in field situations. The effects of these parameters on transformations between readily available and potentially available chemical forms were determined by chemical extractions performed on suspension aliquots from each treatment.

The effects of pH and redox potential on plant availability of trace and toxic metals were determined by growing indicator plant species in sludge-amended soils in which pH and redox potential were controlled.

A secondary objective of the proposed research was to focus on the effects of pH and oxidation-reduction conditions on trace metal complex formation with soluble and insoluble organic matter. This is an important, if not the predominant, regulatory process affecting the availability of metals in sludge-amended soils.

SECTION 2

SUMMARY AND CONCLUSIONS

A laboratory study was conducted using sludge-amended soils to examine the effects pH and especially redox potential (oxidation-reduction conditions) on the levels of selected trace and toxic metals in various inorganic and organic soil chemical forms. Also, relative treatment effects on the availability of these elements to plants were determined.

A study with varying ratios of Chicago reference sludge in a Drummer soil material showed that levels of readily available (exchangeable) and potentially available (organic chelate extractable) chemical forms of most of these elements increased with increasing sludge ratios, as would be expected. In this study of oxidation effects at varying sludge:soil ratios, exchangeable and chelate extractable levels of Cu, Zn, Pb, and Cd were generally greater in oxidized sludge-soil suspensions than in reduced suspensions. One implication of this preliminary study is that soil redox conditions may affect the plant availability of trace and toxic metals in sludge-amended soils.

Two studies were conducted with aerobically and anaerobically digested Baton Rouge municipal sludge to determine whether the method of sewage treatment might affect chemical and plant availability of metals. A preliminary study was conducted, again using several soil-sludge ratios, to determine treatment effects and/or to serve as a basis for a more thorough laboratory experiment for examining this topic. At the 3% sludge ratio, there was some indication that aerobic digestion may increase Cd and Fe in one of three plant species studied in short-term uptake studies. A similar study was conducted with increased replication at one sludge-soil ratio. In this study, the only significant differences were for Cu and Pb in corn, where somewhat greater levels resulted from the anaerobic digestion. But within the constraints of the experimental parameters included in these particular studies, one would conclude that there were no clearly apparent effects of sewage digestion methods on plant availability of the elements examined.

Experiments were conducted to determine effects of oxidation conditions on the distribution of selected elements among humic and fulvic acids and an associated precipitate fraction. There were no consistent, unidirectional changes in concentration of any element with increasing pH and redox potential in any of the three fractions. But Cu levels were generally lower in all three extracted fractions under strongly reduced conditions (-150 mv) compared with better oxidized treatments at pH levels of 5.0 and 6.5. Under

moderately acid conditions, Zn levels in the humic, fulvic, and precipitate fractions tended to decrease with increasing redox potential. Cadmium levels in the fulvic acid fraction generally increased with increasing redox potential values.

The chemical availability and plant uptake studies under controlled pH and redox potential conditions provided considerable information on the forms and transformations of trace and toxic metals in sludge-amended soils.

Various organic phases predominate in retaining Cu under reducing conditions, but as redox potential is increased, a very marked transformation occurs to the reducible (hydrous iron oxide) phase with which potentially available Cu is most strongly associated under well-oxidized conditions. There was a trend for dissolved, exchangeable, and chelate-extractable Cu to increase with increasing redox potential. Results with rice were mixed, but increasing oxidation conditions tended to increase Cu in corn.

In the Chicago sludge-Drummer soil studies, there was a weak trend for readily available (dissolved and exchangeable) Zn to increase with increasing redox potential, and the highest levels were at pH 5.0, as expected. A very large increase in plant zinc levels occurred with increasing redox potential. Most of the potentially available Zn was found in the reducible fraction under oxidized and reduced conditions.

Compared with most other trace and toxic metals studied, a much larger proportion of the total Cd extracted was recovered in the most readily available chemical forms (dissolved and exchangeable). Cadmium appears less strongly associated (immobilized) with high molecular weight organics and, in particular, is weakly bound to hydrous iron oxides. This contributes to a situation in which Cd is readily accumulated by plants grown in Cd-contaminated soils. In most of the experimental combinations of sludge-soil mixtures and pH used in the laboratory microcosms, plant Cd concentrations increased greatly as the redox potential increased.

Lead was most strongly associated with the residual organic phase. Exchangeable Pb was very pH dependent; the greatest levels were found at pH 5.0. Except for the pH effect on exchangeable Pb, changing physico-chemical conditions had little effect on levels of Pb in other chemical forms.

Unlike results with Zn and Cd, oxidation status had little, if any, effect on plant levels of Cr, Ni, and As. Predominant chemical forms in the sludge-amended soils and oxidation effects on levels in these chemical forms are discussed in the report.

Of particular interest, this research does demonstrate the important effects of soil redox potential conditions in regulating the chemical mobility and plant availability of Zn and Cd, two key contaminants in sludge materials that may be applied to soils. Obviously, most crop

species are not grown on soils that range from strongly reduced to well oxidized. Most crops are grown on well-drained (oxidized) soils. Rice is an important exception in that it is normally grown on flooded (reduced) soils. But rice may be grown in upland, oxidized soils as well, and in some regions of the country, substantial acreage is devoted to "dry-land" rice. Sugarcane is grown on soils that are somewhat low and wet, and the redox potentials on these soils would probably be intermediate but subject to frequent and wide fluctuations. Non-agricultural soils may also be used to dispose of sewage sludge, and the oxidation status encountered in various natural habitat soils or other uncultivated soils may vary considerably.

In considering the potential problems associated with the disposal or productive use of contaminated sewage sludges, there are many factors and options to be considered in developing acceptable management plans. This research indicates that the oxidation-reduction status of soils being considered for receiving municipal sludge is an important consideration, particularly for Zn and Cd. In those situations where feasible alternatives exist, wet or poorly oxidized soils would be more effective in immobilizing Zn and Cd; application to these soils would result in less plant accumulation of these metals for most crops or plants in uncultivated habitats.

SECTION 3

LITERATURE REVIEW

PROCESSES REGULATING AVAILABILITY

Oxidation-reduction conditions affect many of the processes that regulate the chemistry and availability of trace and toxic metals. A list of these regulatory processes would include precipitation as insoluble sulfides under highly reduced conditions (Krauskopf, 1956; Engler and Patrick, 1975; Morel et al., 1975), formation of discrete carbonates, metal oxides, or hydroxides of low solubility, (Morel, McDuff, and Morgan, 1973), or adsorption to colloidal hydrous oxides of iron and manganese (Taylor and McKenzie, 1966; Jenne, 1968; Lee, 1973; Windom, 1973; Loganathan, Burau, and Fuerstenau, 1977), primarily in aerobic, neutral or alkaline environments, and complex formation with soluble and insoluble organic matter under all conditions of pH and oxidation intensity (Schnitzer and Skinner, 1966; 1967; Stevenson and Ardakani, 1972; Verloo and Cottenie, 1972; Leland, Shukla, and Shimp, 1973). Because of the high proportion of organic materials in municipal sludge, toxic metal complex formation with soluble and insoluble organics should be especially important processes affecting the availability of toxic metals in sludge-amended soils. Metal chelate formation with soluble organic compounds may enhance the concentration of dissolved metals to levels considerably greater than the concentration of dissolved free ions (Stevenson and Ardakani, 1972). Conversely, complexation with insoluble organics is an important sink immobilizing many toxic metals. This process is significant in sludge-amended soils as it is reported that most of the metals contained in sewage sludge are complexed with insoluble organics (Ardakani, 1971).

Verloo and Cottenie (1972) have demonstrated that soil pH strongly influences the quantities of zinc, copper, lead, and iron which are complexed with soluble humic materials. Others have also shown a significant pH effect on the strength of the metal-organic bond as indicated by the measured stability constant (Tan, King, and Morris, 1971; Schnitzer and Hansen, 1970) and an effect on the relative order of metals ranked according to their stability constants (Schnitzer and Skinner, 1966; 1967).

Currently, there is almost no information available on the effects of short and long term changes in soil oxidation conditions on metal complex formation with humic materials. Oxidation-reduction conditions, and especially a change in the oxidation-reduction environment of soils,

may contribute to important quantitative and qualitative changes in humic substances, thereby affecting the immobilization of toxic heavy metals.

Microbial degradation of organic matter is reported to occur at a faster rate under aerobic soils and sediments compared to anaerobic environments resulting in less organic matter being present in aerobic soils (Reddy and Patrick, 1975). In addition, the structurally complex, high molecular weight compounds characteristic of humic materials in reduced environments are thought to be altered to smaller, less complex molecules with lower metal binding capacity as a soil or sediment is oxidized (Stevenson and Ardakani, 1972; Patrick and Mikkelsen, 1971). Gambrell et al. (1977a) reported that the oxidation of initially reduced river and estuarine sediments increased the levels of dissolved and easily exchangeable cadmium. This increase in the chemical availability of cadmium with sediment oxidation was attributed to the release of cadmium from high molecular weight humic materials.

The literature indicates that many factors influence plant uptake of metals from sludge-amended soils. Crop species, the toxic metal composition of sludge, and sludge application rate are all known to influence metal uptake by crop plants. However, very little published information is available concerning soil physicochemical factors which affect the fixation, mobilization, or plant availability of toxic metals in soils treated with sewage sludge. Soil acidity (pH) and oxidation-reduction status (redox potential) are two important properties known to influence the availability of several metallic and nonmetallic nutrients to plants. For example, Gotoh and Patrick (1972, 1974) reported that both pH and redox potential affected soluble and exchangeable manganese and iron concentrations in rice soils. The readily available levels of these nutrients varied over three orders of magnitude as pH and redox potential were adjusted over the ranges commonly encountered in natural soils and sediments. In addition, recent work has demonstrated the influence of pH and redox potential on regulating chemical transformations which affect the chemical and biological availability of trace and toxic metals in sediments and dredged materials (Gambrell et al., 1977a; 1977b).

The mobilities of iron and manganese are readily affected by changes in pH and oxidation conditions because these parameters affect the valence states of iron and manganese over the range commonly found in nature (Krauskopf, 1972). With some exceptions, such as mercury, most trace and toxic metals generally do not change valence state as their pH-redox potential environment is altered. Nevertheless, the availabilities of all of these metals to living organisms are subject to other regulatory processes affected by pH and redox potential.

Redox potential-pH diagrams illustrating some of these processes and the stability boundaries for common metal compounds in simple aqueous systems are available in the literature for mercury (Hem, 1970), cadmium (Hem, 1972; Price, 1974), zinc (Hem, 1972), and lead (Stumm and Morgan, 1970), as are methods for constructing these diagrams (Stumm and Morgan, 1970; Krauskopf, 1967). An example of a pH-redox potential diagram for

an aqueous system containing mercury and specified levels of a few inorganic ligands is presented below to demonstrate the nature of pH and redox potential control of heavy metal speciation and subsequent solubility (Figure 1). The elemental constituents and thus the number of metallic compounds included in calculations for constructing these diagrams are limited to avoid making the computations unduly complex. Due to the qualitative diversity and quantitative variability of reactive constituents in soils and sediments, the speciation of metals and their availability to plants and other organisms in natural systems are impossible to predict based on theoretical considerations. For example, metal coprecipitation or adsorption to hydrous oxides in oxidized environments cannot be included in these diagrams because little is known of the thermodynamics of the reaction mechanisms. Also, the metal binding capacity of insoluble humic materials cannot be accurately computed and does not fall within neat, well-defined stability boundaries as indicated in simple aqueous inorganic systems (Hem, 1970).

To further complicate matters, the fixation or release of metals induced by a change in soil pH and/or redox potential depends on the composite results of all the regulatory processes affected by these parameters. Some of the processes may be complementary in immobilizing metals. For example, when the redox potential of a system increases above the stability boundary for sulfide for sufficiently long periods, the metals released by the oxidation of sulfide to sulfate may be immobilized again by adsorption to freshly precipitated colloidal hydrous oxides of iron and manganese. Because of the complex interactions between the many regulatory processes, an empirical research approach using representative soil and sewage materials is suggested to determine the influence of pH and redox potential in regulating the mobility and plant availability of heavy metals in sewage sludge applied to soils.

THE EFFECT OF SLUDGE APPLICATIONS ON THE AERATION STATUS OF SOILS

Relatively little data has been published on the effects of sewage or sludge application on the redox potential of soils. However, the reports available suggest that redox potential may decrease after the application of sludge. The intensity of reduction is affected by sludge application techniques (i.e. the use of water as a carrier), rates, and frequency as well as soil properties. The addition of sewage sludge to soils would be expected to affect the oxidation-reduction status of the soil in two ways. A portion of the added organic matter would be available to the soil microbial population and would result in increased oxygen utilization for microbial respiration. Also, Lance, Whisler, and Bouwer (1973) reported that much of the oxygen demand in soils receiving sewage effluent was for nitrification of ammonium nitrogen in the effluent. In addition to increasing oxygen demand, sludge applications may limit gaseous oxygen diffusion into the soil as the soil becomes very wet or flooded and water fills pore space normally occupied by air. Considerable quantities of water may be associated with sludge disposal as piped sewage sludge is usually less than 10 to 15 percent solids (Peterson et al., 1971).

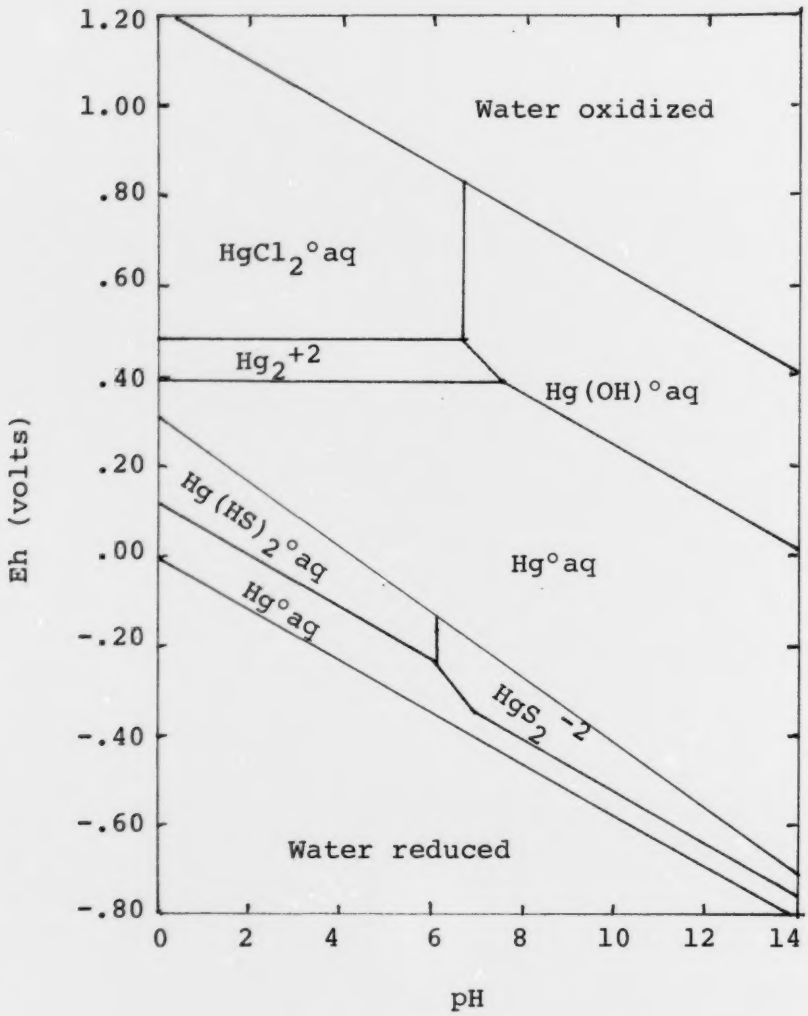


Figure 1. Stability fields for selected mercury species; 25°C, 1 atm, 36 ppm chloride and 96 ppm total sulfur as sulfate (adapted from Hem, 1970).

Whisler, Lance, and Linebarger (1974) reported redox potential measurements on soils receiving secondary sewage effluent containing about 15 to 20 ppm soluble carbon. Redox potential decreased from well oxidized levels (greater than 500 mv) to -100 to -200 mv (strongly reduced) upon infiltration of the waste water. A comparable intensity of reduction was achieved with a solution of 150 ppm glucose carbon, though the rate of reduction was somewhat slower from the sludge carbon source.

In another study of oxygen utilization in soil columns flooded with sewage effluent, Lance, Whisler, and Bouwer (1973) noted more extensive demand for oxygen during longer flooding periods. Five-day drying periods following 2 days of flooding resulted in an increase from mildly reduced (200 to 400 mv) to well oxidized (500 to 700 mv) levels in the upper half of 200 cm columns. However, the lower half remained moderately reduced (0 to 200 mv) throughout the drying period. Extended flooding periods (23 days) resulted in the development of strongly reduced conditions (-100 to -200 mv) at all depths. This research demonstrated that flooding with sewage and subsequent drainage cycles may greatly affect oxidation-reduction reactions.

Klausner and Kardos (1975) found that the application of 5.1 cm of sewage effluent per week did not degrade the aeration status of silt loam and clay loam soils used for oat, hay, and corn rotation.

The results of Whisler et al. (1974), Lance et al. (1973), and those of Klausner and Kardos (1975) suggest that perhaps by selecting soils and managing sewage effluent waste applications and drying time, redox potential may be controlled to some extent if this is found to be desirable for managing the plant availability of trace and toxic metals.

PLANT UPTAKE OF TOXIC METALS FROM SLUDGE-AMENDED SOILS

The inclusion of crop production into a sewage sludge waste treatment program by land application enhances the effectiveness of soil in treating the waste and offers the additional economic advantage of supporting a productive agricultural system. Recovery of plant nutrients and water are particularly attractive aspects of this process as it changes the municipal sewage problem from one of waste disposal to resource utilization. This prospect has become increasingly important as the demand on available water supplies is gradually increased, and especially as the cost and availability of fertilizer have made it more difficult to obtain adequate fertilizer nutrients in recent years (Hueg, 1975).

In the last few years, considerable research data has been generated on the beneficial effects of sewage sludge applications to crop yields. It is generally agreed that with proper management, sewage sludge is a valuable fertilizer for increasing crop yields (Cunningham, Keeney, and Ryan, 1975; King and Morris, 1972; Lunt, 1959; Milne and Graveland, 1972; Peterson et al., 1971; Sabey and Hart, 1975). The nitrogen and phosphorus content of sludge is thought to be the primary factor enhancing crop

yield on sludge-amended soil (Coker, 1966). However, in some studies, significant crop yield reductions have been noted after the application of sewage sludge to soils. Usually, such yield reductions are associated with excessive application rates or with the application of sludge containing large quantities of toxic materials (Lunt, 1959). Heavy metal uptake and subsequent plant toxicity are thought to be contributing in many instances to the observed yield reductions.

In addition to the quantity of literature available on the effects of sewage sludge on various corp yields, a considerable number of publications have reported the heavy metal uptake of crops grown on sludge-amended soils. Many studies have shown the heavy metal content of above-ground tissue of crop plant to be significantly enhanced by metals applied to the soil in sewage sludge applications (Bingham et al., 1975; Boswell, 1975; Cunningham, Ryan, and Keeney, 1975; Dowdy and Larson, 1975a; Mortvedt and Giordano, 1975; Page, 1974). Crop species appear to play an important role (Bingham et al., 1975; Dowdy and Larson, 1975b). Other researchers have reported little or no increase in toxic metal uptake by crops grown on sludge-amended soil. Kirkham (1975) reported that corn grown on soil treated with municipal sludge for 38 years did not appreciably accumulate trace metals in the grain, although considerable quantities of trace metals had accumulated in the soil. Increased levels of cadmium and copper were noted in corn leaves and the levels of most metals were increased in corn roots. Though noting some increase in zinc uptake by corn grown on sludge-amended soil, Mortvedt and Giordano (1975) found that very high levels of chromium applied with sludge failed to increase the chromium uptake by the same plants.

THE EFFECT OF PH AND OXIDATION-REDUCTION CONDITIONS ON TRACE AND TOXIC METAL UPTAKE BY PLANTS

Few studies using carefully controlled pH levels have been conducted to study the effects of pH on heavy metal uptake from sludge-amended soils. However, a number of investigators have measured pH in sludge-amended soils and have suggested pH effects on metal uptake based on differences in pH encountered in the soil and sludge materials studied.

Crop yield reductions on sludge-amended soils occur frequently after excessive applications of sludge containing toxic materials (Lunt, 1959), especially when the sludges are acid forming or are applied to acid soils (Page, 1974; Peterson et al., 1971). Heavy metal toxicity to crop plants is thought in many cases to be contributing to the observed yield reduction.

Dowdy and Larson (1975a) reported on toxic heavy metal uptake by barley seedlings grown on topographically associated soils having pH levels of 5.9 to 7.9. Heavy metal uptake was greater from the sludge-amended acid soil than from the mildly alkaline soil.

Cunningham, Keeney, and Ryan (1975a) noted that sludge applications may alter soil pH, depending on the pH properties of the sludge. They also observed a pH effect on plant uptake. A high lime (pH 7.8) sludge

material containing abnormally high levels of zinc, copper, chromium, and nickel did not adversely affect crop yields, while comparative amounts of a more acid sludge did reduce crop yields because of metal toxicity.

Jones et al. (1975) noted a soil pH effect on the uptake of zinc from sludge-amended soils and a pH effect on cadmium distribution within the grain and leaf tissue.

Lunt (1959) reported that higher yields were obtained from plants grown on soils receiving alkaline sludge than from plants grown on a sludge-amended soil of pH 5.0. Presumably, the greater solubility of toxic metals in the acid soil contributed to the depressed yields.

In an extensive review of the literature on the fate and effects of trace elements in sewage sludge applied to agricultural soils, Page (1974) concluded that pH was one of several factors affecting trace element concentrations in higher plants. The data presented demonstrated that a reduction in soil pH would increase the plant availability of zinc, copper, and nickel.

Lagerwerff (1972), reporting the data of James and Lagerwerff, indicated that mercury uptake by peas grown from seed treated with a mercurial fungicide was slightly greater from acid than from neutral soils. However, little or no pH difference was noted for peas which were not treated with the fungicide, and there were not apparent significant effects of pH on the mercury content of wheat from mercury-treated control seed.

Several investigators have reported that liming decreased the foliar lead content of plants grown on lead-contaminated soils (John and VanLaerhoven, 1972; Cox and Rains, 1972). MacLean, Halstead, and Finn (1969) suggested that greater complexing capacity of the soil organic matter as pH increased accounted for decreased plant availability of lead in limed soils. Zimdahl and Foster (1976) noted that liming decreased the uptake of lead by corn and reduced lead translocation within the plant. Numerous others have reported an inverse relationship between plant uptake of lead and pH (Griffeth, 1919; Page and Ganje, 1972; John, 1972; MacLean, Halstead, and Finn, 1969; Miller, Hassett, and Koeppe, 1975; Arvik and Zimdahl, 1974); the same phenomenon has been observed for cadmium (Miller, Hassett, and Koeppe, 1976; Lagerwerff, 1971; John et al., 1972).

Some studies have shown cadmium availability to be strongly influenced by soil cation exchange capacity (John and VanLaerhoven, 1972; John, VanLaerhoven, and Chuak, 1972; Haghiri, 1974). However, a more recent synthesis of the literature suggests that cation exchange capacity generally indicates the role of other soil components that affect cadmium mobility and is itself not a valuable parameter for estimating cadmium availability (CAST, 1980). Gambrell et al. (1977a) have shown that exchangeable cadmium levels are strongly influenced by pH in oxidized sediment-water systems, but less affected by pH under reduced conditions.

Although there are numerous publications reporting the effects of soil pH on plant uptake of trace and toxic metals, there is only limited information on the effects of soil oxidation-reduction conditions in trace and toxic metal uptake by plants.

Weeraratna (1969) reported that manganese uptake by rice from wetland soils was greater under flooded conditions than under unflooded conditions. Manganese uptake from an upland soil was lower under flooded conditions than under unflooded conditions, but this was thought to result from increased iron availability and subsequent iron toxicity to plants grown in the flooded, upland soil. Where manganese availability was increased by flooding, it was attributed to the increased levels of soluble manganese in reduced (flooded) soils.

Clark, Nearpass, and Specht (1957) also reported that manganese availability to rice was increased by submerged soil conditions.

Mandal (1962) reported on yield and the nitrogen, iron, and manganese content of rice as a function of the oxygen content of the atmosphere overlying the floodwater. The anaerobic and semianaerobic (0 and 10% oxygen) treatments resulted in a greater accumulation of both iron and manganese in the shoot tissue than was found in the semiaerobic and aerobic treatments. The aerobic treatments were thought to favor stability of the sparingly soluble oxides and hydroxides of these metals, reducing their availability to plants.

Jones and Etherington (1970) reported on the effects of waterlogging on the uptake of iron and manganese by two marsh species (Erica cinerea and Erica tetralix) in a study to determine factors favoring the establishment of E. tetralix on wetter sites. Waterlogging enhanced the uptake of manganese by leaf tissue of E. cinerea; both species accumulated significantly more iron in both shoot and root tissue from waterlogged soils than from the control treatment.

Kothny (1973) reported that the plant availability of mercury is decreased in reducing soils (negative redox potential). Suggested mechanisms of mercury retention by soils under anaerobic conditions included insoluble complex formation with soil organics and sulfide.

Mikkelsen and Brandon (1975) reported that zinc deficiency in rice is observed to be more severe in submerged soils than in surface irrigated soils, especially when crop residues are undergoing active decomposition. Though no direct reference is made to the effects of flooding and residue decomposition on soil redox potential, it is probable that the zinc deficiency problems noted were related to the oxidation-reduction conditions of these soils.

Jugsujinda (1975) found that the uptake of iron, manganese, and zinc was strongly influenced by redox potential and pH in a laboratory study in which these parameters were controlled. Labelled iron uptake was high under anaerobic conditions at low pH. Labelled manganese uptake was considerably greater under reduced conditions at both pH 5.5 and 7.5.

Zinc uptake was reduced as pH increased in incremental units from 5.0 to 8.0. Zinc uptake was greater in aerobic soil than in anaerobic soils at each pH level studied.

The lower zinc content of plants grown under anaerobic conditions compared to aerobic conditions was attributed to the formation of insoluble zinc sulfide and possibly to the production of more stable metal-organic complexes under anaerobic conditions.

In a literature review, Lucas and Knezek (1972) reported that mixed effects of poor aeration on zinc availability to plants have been found. However, much of the available literature indicates zinc is less available to plants in anaerobic soils (Mikkelsen and Brandon, 1975; IRRI, 1970; Jugsujinda, 1975).

Kirkham (1975) reported that cadmium accumulation in barley roots grown on sludge-amended soil was inversely proportional to the cadmium retained in sludge crusts, which, in turn, depended on sludge application frequency. Though no redox potential measurements were made, processes affected by redox potential seemed to be involved; it was stressed that application frequency strongly influenced the wetting and drying cycles in the upper soil layer and sludge crust.

Bingham et al. (1976) reported on the γ-leaf content of cadmium, copper, iron, manganese, and zinc in rice grown under flooded and nonflooded conditions in a soil amended with 1 percent sewage sludge enriched with variable levels of cadmium. Grain yield was reduced at 17 μg Cd/g under nonflooded conditions, while 320 μg Cd/g did not adversely affect grain yield under flooded conditions. Leaf cadmium levels were slightly greater under nonflooded management. In this study, the leaf content of iron and zinc were found to be higher by a factor of about 0.5 to 2 under flooded conditions, while flooding increased managanese content manyfold. The leaf copper content was little affected by soil flooding.

These authors attributed the increased plant tolerance and reduced availability of cadmium in flooded soils to precipitation of cadmium sulfide. However, they do not explain why sulfide precipitation failed to reduce zinc availability under flooded conditions. Gambrell et al. (1977a), working with four river and coastal sediments, reported that the chemical availability of cadmium is enhanced by sequential oxidation of sediment-water systems above the critical potential for sulfide stability. Increased cadmium release from sediment organics with increasing oxidation intensity apparently contributed to the higher levels of cadmium in soluble and exchangeable forms.

Ito and Iimura (1975) reported that the cadmium content of rice plants increased only slightly with increasing cadmium additions to submerged soils in pot experiments. However, under oxidizing conditions, the cadmium content of rice plants increased markedly with cadmium additions. Cadmium concentration in the soil solutions ranged from approximately 0.1 μg Cd/ℓ in the submerged soil to 10 μg Cd/ℓ in the drained soil.

Reddy and Patrick (1977) reported that an increase in the redox potential of a Mhoon soil suspension increased the uptake of cadmium by lowland rice to a considerable extent. In this study, lead uptake was enhanced by lowering the pH, but unaffected by changes in redox potential.

In a study of the effects of controlled pH and oxidation-reduction conditions on trace and toxic metal uptake by marsh plants, Gambrell et al. (1977b) reported that cadmium and zinc uptake were enhanced by an increase in soil oxidation levels.

From the literature, it is apparent that the various processes affecting metal availability in soils are influenced by both redox potential and pH. A study in which both of these parameters are controlled at specified levels covering the ranges normally encountered in soils would be helpful in understanding how soil conditions affect the plant availability of metals applied with sludge. Currently, little information is available in the literature on the effect of pH on this topic, and essentially no information has been published regarding the influence of soil redox potential on mobilization of sludge-bound toxic heavy metals.

SECTION 4

MATERIALS AND METHODS

INTRODUCTION

The procedures used in many of the laboratory studies were very similar. For most experiments, only such parameters as duration of the incubation, pH, soil and sludge materials used, and plant species used for uptake studies varied. Therefore, the source of materials and general procedures used for the controlled incubations, chemical extractions, plant uptake studies, and analytical procedures will be described first. A description of the experimental parameters for the individual laboratory experiments will follow.

SLUDGE AND SOIL SOURCES

Chicago Reference Sludge

Chicago reference sludge material was obtained from Dr. Jim Davidson of the University of Florida at Gainesville. Grinding was the only additional preparation required before using this material in the laboratory microcosms.

Baton Rouge Municipal Sludge

Approximately 120 liters of raw sludge was collected from the Baton Rouge Central Sewage Treatment Plant and transported to the laboratory in large plastic containers. The sewage was divided into two equal portions. Half was anaerobically digested in sealed plastic carboys for six weeks. Excess gas pressure was released twice daily by inserting a stainless steel syringe needle through a rubber septum mounted in the carboy cap. After venting, the vessels were rolled on a roller/mixer for about 10 minutes to maintain near-uniform conditions of the contents during the anaerobic digestion. The other half of the raw Baton Rouge sewage was aerobically digested by means of continuous mechanical stirring and injection of industrial grade oxygen. After six weeks of digestion, both the aerobically and anaerobically digested materials were dewatered, dried, and finely ground.

Drummer Silty Clay Loam Soil Material

The Drummer silty clay loam soil material was obtained from Dr. Robert Pope, Agricultural Extension Service, University of Illinois. This material was finely ground for use in the various laboratory studies.

Loring Silt Loam Soil Material

A Loring silt loam soil material was collected from a wooded area within Baton Rouge. Classification was based on soil survey maps (Dance et al., 1968). The surface (A) horizon collected was dried, ground, and well mixed for subsequent laboratory studies.

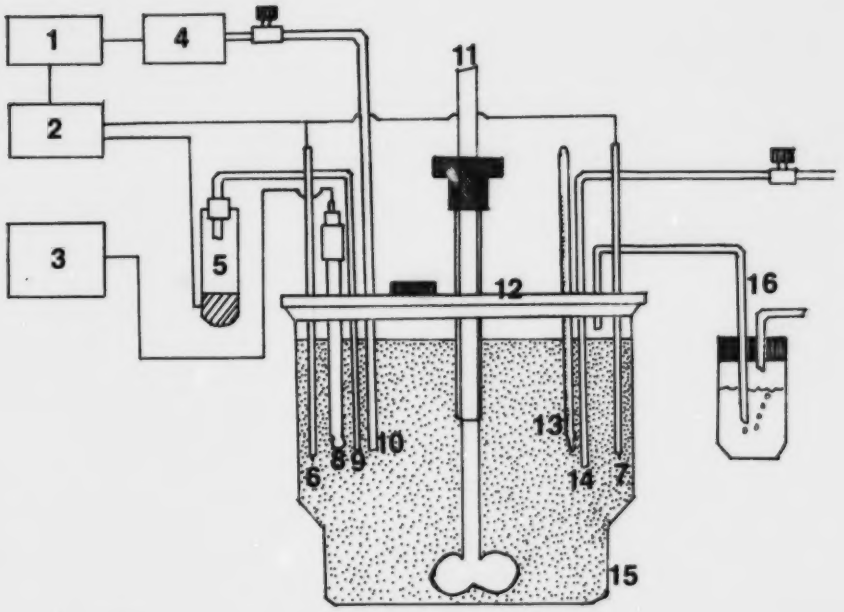
INCUBATIONS OF SLUDGE:SOIL SUSPENSIONS UNDER CONTROLLED pH AND REDOX POTENTIAL CONDITIONS

A small (approximately 4-liter) opaque desiccator was used to contain the aqueous suspensions of sludge-soil mixtures incubated under controlled pH and redox potential conditions (Figure 2). Thirty g of sludge, 270 g of soil, and 1500 ml of deionized water were placed in each desiccator to achieve a water-to-solids ratio of 5:1.

A plexiglass plate with several holes was sealed over the top of the desiccator. Stirring was accomplished by means of a Nalgene linear polyethylene-coated four-blade stirrer which was passed through a 3/8" glass tube fixed in the desiccator cover. To prevent the diffusion of air into the suspension between the stirring rod and the glass tubing, a hole slightly smaller than the shaft of the stirrer was bored in a rubber septum. This septum was placed over the end of the glass tubing with the shaft protruding from it; a seal was maintained with glycerine. The stirring shaft was driven by an electric, direct-drive, variable speed mixer. Each incubation vessel was equipped with a glass combination electrode for measuring pH, two platinum electrodes for measuring redox potential, a thermometer, a large rubber septum, separate inlets for air and oxygen-free nitrogen, and an outlet tube, the end of which was submerged in water to prevent atmospheric oxygen from diffusing into the flask.

Suspension pH was adjusted to the desired level and then maintained by using a syringe to add 2N sodium hydroxide or hydrochloric acid as required through the rubber septum. A combination pH electrode equipped with an annular (encircling the electrode body) ceramic junction for the reference electrode was found to be very stable for these studies (required infrequent recalibration) compared to electrodes with a small ceramic dot-type junction, which appear to quickly clog with fine clay particles or metal sulfides contributing to high and changing junction potentials.

Bright platinum electrodes were connected to a Beckman Zeromatic IV pH/millivolt meter for measuring redox potential; a saturated calomel reference electrode completed the electrochemical cell. Automatic control



1. meter relay
2. pH/Eh meter
3. pH meter
4. air pump
5. calomel half cell
6. platinum electrode
7. platinum electrode
8. pH electrode
9. salt bridge
10. air inlet
11. stirrer
12. plexiglass plate
13. thermometer
14. N_2-inlet
15. desiccator
16. gas outlet

Figure 2. Laboratory microcosm used to maintain soil suspensions under controlled pH and redox potential conditions.

of redox potential was achieved by connecting a meter relay (General Electric, Type 196) to the recorder output of the millivolt meter. The meter relay activated an air pump whenever the redox potential of the suspension decreased below a preset level. The air-flow rate was regulated between 0.5 and 2.0 ml/minute to give slow oxidation of the suspension during the add-air cycle. Once the suspension returned to the preset redox potential level, the relay switched off the air pump. Oxygen-free nitrogen gas was continuously purged through the suspensions to flush excess oxygen from the system at the end of the aeration cycle and to prevent a buildup of gaseous decomposition products. Using this system, the redox potential could be maintained within 10 to 30 millivolts of the desired potential.

EXTRACTION PROCEDURES FOR CHEMICAL AVAILABILITY STUDIES

General

Five selective chemical extractions were used to determine the effects of experimental parameters on the levels of trace and toxic metals in specific chemical forms: 1) water soluble, 2) exchangeable, 3) reducible, 4) organic bound recovered by a chelating agent, and 5) residual organic bound. It has been reported that levels of soluble and exchangeable metals in anaerobic systems can be rapidly and substantially altered by even brief exposure of the water or extract solution to air. To preserve sample integrity and eliminate experimental artifacts due to sample processing, it is necessary to conduct certain of the extractions of reduced samples under an inert atmosphere. This procedure will be described below.

Water soluble

This fraction included free ions as well as complexed ions that would pass through a 0.45 micron membrane filter. Approximately 150 ml of the sludge:soil suspension was withdrawn from the incubation vessel through the rubber septum using a large capacity glass syringe fitted with a 1-ml glass pipette in place of a needle. The sample aliquot was transferred to a tared, nitrogen-filled, airtight, 500-ml, polycarbonate centrifuge bottle which was fitted with a rubber septum in the cap. The centrifuge bottle was reweighed to determine the weight of the suspension; the mass of solids present was calculated from this value and a previous moisture content determination. The suspensions were centrifuged at 7,000 rpm for 30 minutes, and the supernatant solution filtered through a 0.45 micron membrane filter into a receiving flask containing sufficient concentrated, distilled nitric acid to reduce the pH to <2 as a sample preservative. Centrifugation and filtration of all but the most oxidized samples were done under an oxygen-free nitrogen atmosphere as described elsewhere.

Exchangeable

A 2-N ammonium acetate solution was prepared and shaken with sufficient cation chelating resin (Chelex-100, ammonium form, 100-200 mesh) to remove trace metal contamination in the reagent. Before use, this extracting solution was filtered, diluted to 1N and adjusted to the pH of the sample with distilled, deionized water and acetic acid. Sufficient extractant to give a 10:1 extractant:solids ratio (weight basis) was poured into the centrifuge bottle containing the densely packed residual solid material from the water soluble extraction. The bottle was quickly capped and purged with N_2. Dissolved oxygen was removed from the extracting solution as described elsewhere, and the sludge-amended soil sample was extracted by continuous shaking of the centrifuge bottles for two hours on a box shaker. The sample was then centrifuged, filtered, and acidified as described for the water soluble fraction except that substantially more nitric acid was required to lower the pH for preservation of the sample due to the buffering capacity of acetate solutions.

Reducible

A solution of 0.15 M oxalic acid and 0.25 M ammonium oxalate was cleaned of trace metal contamination by treatment with an ammonium-saturated chelating resin as described for the exchangeable extraction. Sufficient oxalate extractant was added to the residual sludge-soil sample from the exchangeable metals step to give an extractant:solids ratio of approximately 10:1. The procedure for subsequent extraction and sample processing was the same as described previously for the exchangeable fraction except that by this step, filtration under an inert atmosphere was not necessary.

DTPA (diethylenetriaminepentaacetic acid) Extractable

An extracting solution of 0.05 M DTPA (except for Experiment N in which a 0.005 M solution was used) in 0.2M sodium acetate was adjusted to pH 7.0, and an amount equivalent to a 10:1 extractant:solids ratio was added to the residual sludge-amended soil from the reducible extraction. This fraction was not extracted or filtered under an inert atmosphere. No sample preservative was required other than refrigeration if the samples were going to be analyzed within a few days as all of the trace metals present would be strongly complexed in the chelate solution.

Residual Organic Bound

The residual sludge-amended soil solids from the DTPA extraction were dried, ground, and digested at 95°C first with 1:1 HNO_3, then with concentrated HNO_3, and finally with a 30 percent hydrogen peroxide solution for several hours until the organic matter was destroyed (as indicated by lighter color of the solid phase). An acid extract was diluted to volume and analyzed for elements of interest.

Chemical Extraction under an Inert Atmosphere

In studies in which oxidation-reduction conditions may affect chemical transformations of trace and toxic metals, the oxidation status of the samples should be maintained during sample processing steps to maintain sample integrity. This is especially important when extracting anaerobic soils for dissolved and exchangeable metals. The oxidation of soluble ferrous iron, which is stable under reducing conditions, to insoluble ferric oxyhydroxides, may occur quickly when dissolved oxygen is introduced into a previously anoxic aqueous sample (Windom, 1972). Freshly formed ferric oxyhydroxides are believed to be effective scavengers for many trace and toxic metals (Jenne, 1968; Lee, 1973; Windom, 1972). Therefore, exposure of anoxic samples to air in the laboratory during sample processing may contribute to erroneous results and precautions should be taken to minimize oxidation of samples during sample processing.

In this project, reduced or anaerobic samples were processed under an oxygen-free nitrogen atmosphere. Centrifuge bottles used for sample processing were purchased with gas-tight caps; each of these caps was fitted with a silicone rubber septum to allow the transfer of solutions and nitrogen to and from the bottle without exposing the sample to air. Prior to receiving a suspension sample from the experimental microcosms, the centrifuge bottles were purged with nitrogen. A 50-ml glass syringe on which the needle was replaced with a 1-ml glass pipette was flushed with nitrogen, then used to transfer sample aliquots from the incubation vessels to the centrifuge bottles. After centrifugation to obtain the water soluble fraction, the supernatant was transferred under a nitrogen atmosphere to a sealed filtration apparatus which had been previously purged with nitrogen (see Figure 3 for details). After passing through the 0.45 micron membrane filter, the filtrate mixed with concentrated nitric acid already present in the base of the filtration unit as a sample perservative for most extractions. Once the filtrate was swirled to thoroughly mix with the acid, the sample could be poured into polyethylene bottles for storage until the solutions were analyzed.

After collecting the water-soluble fraction, additional extractions in the sequential fractionation procedure were also conducted under a nitrogen atmosphere. A measured quantity of the next extracting solution (i.e., 1N ammonium acetate) was poured into the centrifuge bottle while the residual solids from the previous extraction were still packed in the bottom of the centrifuge bottles. The sealing cap was replaced and the centrifuge bottle immediately connected to a vacuum pump and an oxygen-free nitrogen source by means of tubing and a stainless steel needle inserted through the rubber septum. A strong vacuum was applied until and for a minute after the extracting solution approached a boil (as indicated by the formation of gas bubbles within the solution). The atmosphere in the centrifuge bottle was then replaced to just over 1-atmosphere of pressure with oxygen-free nitrogen gas. This sequence was repeated five times to remove gaseous and dissolved oxygen before shaking the bottle to break up the compacted centrifuged solids and disperse the solids into the extracting solution.

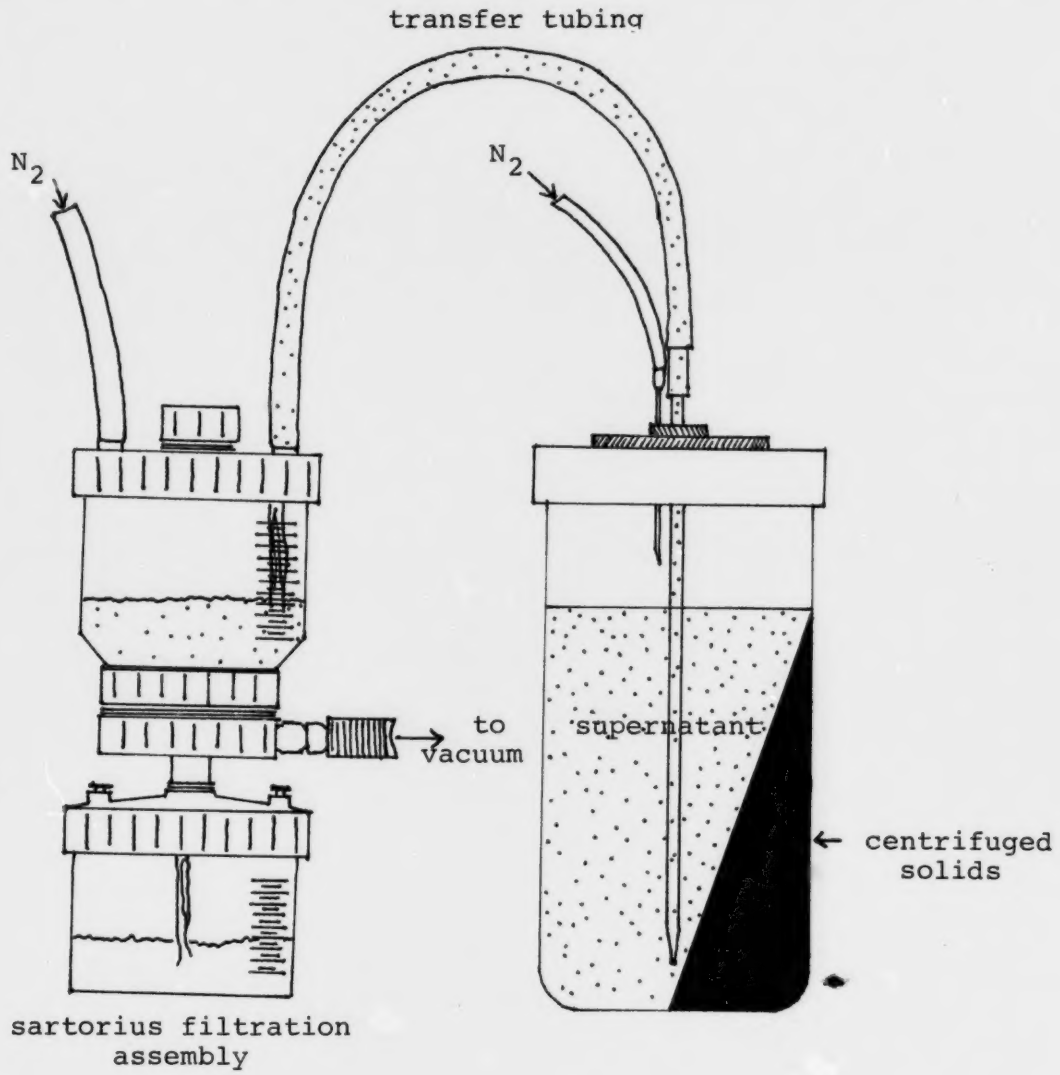


Figure 3. Centrifuge bottle and filtration cell used to filter samples under an O_2-free, N_2 atmosphere.

Extraction of Humic Acid, Fulvic Acid, and a Precipitate Fraction from Sludge-Soil Mixtures

Sludge or sludge-soil suspensions were dried at 55°C and ground to a fine powder in a mortar and pestle. A 100 g aliquot of the sludge-soil mixture was placed in a 2 ℓ Nalgene bottle and mixed with 500 ml of oxygen-free 0.5 N NaOH. After purging the bottle with N_2 for twenty minutes, the bottle was placed on a roller for 16-18 hours. The suspension was then transferred to a beaker and dispensed into 50 ml polyethylene centrifuge tubes for twenty minutes of centrifugation at 27,000 g. The supernatant was collected and centrifuged again, then collected and centrifuged a third time for a total of three, twenty-minute intervals. The residual solids were discarded each time, though essentially all of the solids removed from the extract were removed with the first centrifugation. The decanted solution was acidified to pH 1.0, using concentrated HCl until pH 5.0 was reached, and then 6.0 N HCl added dropwise. The beaker was covered and allowed to stand at room temperature for one hour to allow the humic acid fraction to coagulate. At the end of the hour, the solution was centrifuged at 27,000 g for fifteen minutes. The fulvic acid supernatant was collected and the precipitated humic acid rinsed into a beaker with distilled, deionized water (Holtzclaw et al., 1976).

To separate the aluminum and iron phosphate contaminants from the fulvic acid fraction, the pH of the solution was increased from 1.0 to 5.65 by adding 5 N NaOH. The solution was allowed to stand for two hours and then centrifuged to separate the fulvic acid solution from the aluminum and iron phosphate solids (Holtzclaw et al., 1978).

All three fractions were finally dried over a steam bath and reduced to a powder with an agate mortar and pestle.

PLANT UPTAKE STUDIES

For certain experiments, plant uptake studies were done after the chemical fractionation samples were withdrawn from the microcosms. Plant seedlings were introduced to the incubation vessels and grown for two weeks to examine pH and especially redox potential effects on the availability of trace and toxic metals to plants grown in sludge-amended soils. Corn, rice and soybean seeds were germinated in petri dishes filled with water (the water was changed twice daily). Sprouted seeds were transferred to plastic cups filled with damp sand and watered twice daily, once with nutrient solution and once with water. A drain near the bottom of the cup prevented waterlogging and mold growth. Once the shoots reached a height of approximately 2 inches, the seedlings were fixed with electrical grade silicon sealant* into plexiglass plates, with the

*The electronics grade silicone seal has an ethanol base which does not kill the plants as does the common caulking formulations of silicone rubber which contains an acetic acid base.

roots suspended in pots of nutrient solution (Shen's medium). The plants were grown under incandescent and florescent lighting. When the seedlings reached a height of between 10 and 20 cm, the plexiglass plates in which they were mounted were substituted for those currently in place on the experimental microcosms. The various electrodes, stirring assembly, and gas tubes were fitted into the new plate and sealed. Now the plant roots were immersed in the sludge-amended soil suspension maintained under controlled pH and redox potential conditions. The plants were grown in the sludge-soil suspension for a 2-week period under mixed incandescent and florescent lighting. After 2 weeks, the stem and leaf tissue was harvested, dried at 70°C, cut into small pieces with stainless steel scissors, weighed, and digested in hot, distilled nitric acid for metal analyses. Although several attempts were made, we were unsuccessful in getting soybeans to live after being transplanted into the sludge-soil suspensions.

SAMPLE ANALYSES BY INDUCTIVELY COUPLED ARGON EMISSION SPECTROMETRY

Samples from early experiments in this study were analyzed by flame atomic absorption spectroscopy (AA) for Fe, Mn, Cu, Zn, Pb, Cd, Cr, and Ni. In the water soluble and exchangeable fractions, levels were frequently too low for detection by flame absorption methods, and samples were analyzed by anodic stripping voltammetry (ASV) for Cu, Cd, and Pb. About half-way through the study, the Laboratory initiated the purchase of a Jarrell-Ash Model 855 inductively coupled argon plasma emission spectrometer (ICAP). Although a substantial amount of time, effort, and money had been expended in analyzing samples up to that time by AA and ASV, it was decided to use the ICAP to analyze all samples obtained in the project. Certain of the samples which had been stored for extended periods had deteriorated (i.e., precipitation of humic materials in acidified water samples and some suspended fungus-like strands in DTPA samples stored for months under refrigeration). Thus all water and chemical extracts were: 1) sonicated with a stainless steel ultrasonic probe, 2) transferred to glass digestion tubes, then 3) digested in hot, distilled nitric acid. Similar treatment of water blanks indicated no significant contamination occurred during this additional sample processing.

The ICAP used for sample analysis was equipped with detectors for Cu, Zn, Cd, Pb, Cr, Ni, As, Fe, Mn, Ca, Mg, Mo, Si, P, Al, Na, and K. The samples were analyzed for all of these but Na and K. Extensive work with the spectrum shifter background correction option indicated that its use did not affect the output levels significantly with the exception of an interference of Al on As. This problem was present to some extent even with background correction, and was resolved by programming a correction factor (interelement interference correction) into the computer.

Additional instrument operating parameters are given below:

TABLE 1. OPERATING CONDITIONS FOR ICAP

Parameter	Notes
Forward RF power	1,100 watts
Forward power control	automatic
RF load tuning	automatic
Nebulizer	Jarrell-Ash fixed cross flow used without perstaltic pump
Spectrum shifter (automatic background correction)	off
Spectrum alignment adjustments	profiled twice daily with Hg lamp
Interelement interference corrections	As levels corrected for Al interference
Sample feed	manual
Standardization	checked calibration about every 10 samples and restandardized as necessary
Source of Stock Standards	commercial atomic absorption standards
Working Standards	#1. pure water blank #2. 10 ppm Fe, Mn, Ca, Mg, Al, Mo, Cu, Zn, Pb, Cd, Ni, As #3. 10 ppm P, Si, and Cr

Stock atomic absorption standards were used to prepare working standards after checking to see that each standard did not contribute significant signals for other elements of interest due to presence of impurities or other elements in the standard formulation. For example, a P standard was prepared from KH_2PO_4. The K content must be known and compensated for if one is interested in both K and P. To check for interelement interferences, especially from elements (such as Fe and Al) present in high concentrations in some of our samples, standards were prepared from high purity metals and run. As mentioned elsewhere, the only significant problem found was the interference of Al on As. Linearity was checked up to 200 ppm for Fe, Ca, Mn, Mg, Al, and P and 100 ppm for the remaining elements. If any solution aspirated into the instrument exceeded the upper levels for which linearity was confirmed, the sample was diluted and run again for those particular elements.

Table 2 lists concentrations of various elements certified to be in a water sample (Trace Elements in Water, Standard Reference Material 1643a, National Bureau of Standards, U. S. Department of Commerce). Also given are the levels found using the Laboratory for Wetland Soils and Sediment's ICAP and calibration standards.

TABLE 2. COMPARISON OF ICAP ANALYSIS AND CERTIFIED LEVELS OF ELEMENTS IN A WATER SAMPLE (NBS STANDARD REFERENCE MATERIAL 1643A)

Element	ICAP	NBS Certified Levels
	mg/ℓ	
Cu	0.111	0.018±2
Zn	0.072	0.072±4
Cd	0.012	0.010±1
Pb	0.035	0.027±1
Cr	0.019	0.017±2
Ni	0.056	0.055±3
As	0.092	0.076±7
Fe	0.083	0.088±4
Mn	0.030	0.031±2
Ca	25.85	27.00
Mg	7.42	8.00
Mo	0.105	0.095±6
Si	0.034	†
P	0.001	†
Al	0.065	†

†NBS levels not reported.

Table 3 gives a similar comparison using Orchard Leaves (Standard Reference Material 1571, National Bureau of Standards, U. S. Department of Commerce). The standard orchard leaves were digested as previously described and analyzed on the ICAP using laboratory standards for calibration. With the exception of P, only elements present in concentrations below 100 ppm were reported because the necessary additional dilution was not done on the orchard leaves to bring levels within the linear range of the instrument.

All of the ICAP analyses were reasonably close to the certified levels with the exception of Cu in the water sample (0.11 vs. 0.018±2). Using the same calibration standards for the orchard leaves analysis, the Cu levels were very close (13.6 vs. 12±1) thus the water sample may have been contaminated with copper in pouring out an aliquot for analysis.

SUMMARY OF INDIVIDUAL EXPERIMENTS

Experiment A: Sludge Ratio Study

A preliminary study was conducted in which mixtures of Chicago reference sludge and Drummer soil were incubated as suspensions under conditions of continuous air purging or oxygen-free nitrogen purging. The sludge:soil ratios used were: 0:100, 5:95, 25:75, and 100:0. At the end of the incubation, sequential extractions were made on the

TABLE 3. COMPARISON OF ICAP ANALYSIS AND CERTIFIED LEVELS OF ELEMENTS IN ORCHARD LEAVES (NBS STANDARD REFERENCE MATERIAL 1571)

Element	ICAP	NBS Certified Levels
	mg/kg	
Cu	13.6	12±1
Zn	22.0	25±3
Cd	0.10	0.11±0.01
Pb	35.2	45±3
Cr	3.75	2.6±0.3
Ni	1.15	1.3±0.2
As	9.6	10±2
Mn	71	91±4
Mo	0.19	0.30±0.10
P	2,040	2,100±100

suspensions to measure water soluble, exchangeable, and DTPA extractable levels of selected elements to determine the effects of sludge soil ratios and oxidation conditions on the chemical availability of these elements.

Experiment B: Extraction Sequence Study

A study was conducted varying the sequence of the extraction solutions used to determine the general geochemical form of elements in soils. The general chemical forms examined were: water soluble, exchangeable, reducible, and DTPA extractable. The study was done at two sludge ratios (0 and 25 percent) and two redox potential levels (oxidized and reduced) using Chicago reference sludge and Drummer soil material.

Experiment C: The Effects of Controlled Redox Potential and pH on Levels of Selected Elements in Different Chemical Forms and in Rice Tissue Grown in a Suspension of Chicago Reference Sludge (10%) and Drummer Soil Material

A 10% mixture of Chicago reference sludge and Drummer soil material was incubated at pH 6.5 and four redox potential levels (-150, 50, 250, 500) ranging from strongly reduced to well oxidized. The elements measured were Cu, Zn, Cd, Pb, Cr, Ni, As, Fe, Mn, Ca, Mg, Mo, Si, P, and Al, although for purposes of this study, discussion of results focused on those trace and/or toxic elements potentially posing the greatest risk of adverse health effects in sludge-amended soils. The general chemical forms extracted included water soluble, exchangeable, reducible, and DTPA extractable.

Experiment D: Effect of Aerobic or Anaerobic Sewage Digestion on the Chemical Availability and Plant Concentration of Trace Elements

A study was conducted in which corn, rice, and soybeans were grown for a few weeks in a Loring silt loam soil material amended with 0, 1, 2, 3, and

5 percent sludge. Raw sewage was collected from the Baton Rouge Central Treatment Plant, divided into equal portions, partially dewatered, then one portion was digested anaerobically and the other aerobically. Half of the experimental units received anaerobically digested Baton Rouge sludge, and the remainder received aerobically digested Baton Rouge sludge. Corn, rice, and soybean seedlings were grown in these sludge-amended soils for about 2 weeks and levels of selected elements measured in the above-ground plant tissue as well as in water soluble, exchangeable, and DTPA extractable forms.

Experiment E: The Effects of Controlled Redox Potential and pH on Levels of Selected Elements in Different Chemical Forms and in Rice Tissue Grown in a Suspension of Chicago Reference Sludge and Drummer Soil Material

This study was similar to Experiment C except that pH was maintained at 5.0 in the sludge-soil mixtures.

Experiment F: The Effects of Controlled Redox Potential and pH on Levels of Selected Elements in Different Chemical Forms and in Rice Tissue Grown in a Suspension of Chicago Reference Sludge and Drummer Soil Material

This study was similar to Experiment C except that pH was maintained at 8.0 in the sludge-soil mixtures.

Experiment G: Trace and Toxic Elements in Humic and Fulvic Acids

Two studies were done with elements in humic materials. In one, levels of selected elements in humic, fulvic, and precipitate forms were determined in Baton Rouge sludge materials which had been prepared by either an anaerobic or an aerobic digestion process.

In the other study, levels of selected elements in the three humic materials were determined in extracts of many of the sludge-soil suspensions incubated under controlled pH and redox potential conditions. The extraction methods used are described elsewhere in this report.

Experiment I: The Effects of Controlled Redox Potential and pH on Levels of Elements in Different Chemical Forms and in Corn Tissue Grown in a Suspension of Chicago Reference Sludge and Drummer Soil Material

This study was similar to Experiment C except that corn was grown instead of rice and the sludge-soil suspensions were maintained under controlled redox and pH conditions for 6 weeks prior to sampling rather than the usual 2.

Experiment J: The Effects of Controlled Redox Potential and pH on Levels of Selected Elements in Different Chemical Forms and in Corn Tissue Grown in a Suspension of Chicago Reference Sludge and Drummer Soil Material

This study was similar to Experiment C except that corn was grown instead of rice and the sludge-soil suspensions were maintained at pH

5.0. Because of this low pH, it was not possible to achieve an Eh of -150 mV, so only redox potentials of 50, 250, and 500 mV were reported.

Experiment K: The Effects of Controlled Redox Potential and pH on Levels of Selected Elements in Different Chemical Forms and in Corn Tissue Grown in a Suspension of Chicago Reference Sludge and Drummer Soil Material

This study was similar to Experiment C except that corn was grown instead of rice and the suspensions were maintained at pH 8.0.

Experiment L: The Effects of Controlled Redox Potential and pH on Levels of Selected Elements in Different Chemical Forms and in Rice Tissue Grown in a Suspension of Chicago Reference Sludge and Loring Loam

This study was similar to Experiment C except that Loring loam was substituted for the Drummer soil material in the sludge:soil mixture.

Experiment M: The Effects of Controlled Redox Potential and pH on Levels of Selected Elements in Different Chemical Forms and in Rice Tissue Grown in a Suspension of Chicago Reference Sludge and Loring Loam

This study was similar to Experiment C except that pH was maintained at 8.0 and Loring loam was substituted for the Drummer soil material in the sludge:soil mixture.

Experiment N: The Effect of Aerobic and Anaerobic Digestion of Baton Rouge Sewage on the Concentration of Selected Elements in Corn and Soybean Plants Grown on a 5 Percent Sludge-Amended Drummer Soil Material

The objectives of Experiment D were to examine whether an aerobic or anaerobic digestion of sewage influenced the chemical availability or plant uptake of trace and toxic elements in sludge-amended soils. Upon examining the results of Experiment D, it was decided to repeat it including fewer experimental parameters and more replication. Soybean and corn seedlings were grown for 3 weeks in the Drummer soil material amended with 5 percent of aerobically or anaerobically digested Baton Rouge sludge. Only the plant tissue samples were analyzed for elemental content. Each experimental combination was replicated five times.

SECTION 5

RESULTS AND DISCUSSION

EXPERIMENT A: SLUDGE RATIO STUDY

Sludge-soil mixtures were incubated as suspensions under conditions of continuous air purging or oxygen-free nitrogen purging. The sludge: soil ratios used were: 0:100, 5:95, 25:75, and 100:0. At the end of the incubation, sequential extractions were done to measure selected elements in the water soluble, exchangeable, and DTPA extractable forms to examine the effects of oxidation conditions and sludge:soil ratios on the levels of elements in these forms.

The data suggested that at sludge ratios of 75 and 100 percent, oxidizing conditions were probably not achieved. Therefore, the evaluation of the results will be limited to the 0, 5, and 25 percent sludge ratios. An examination of the data also indicated that for every one of the 12 elements measured, the total water soluble levels in the 5 percent sludge incubations were always much higher from the reduced suspension than from the oxidized suspension. This suggests a sampling problem with one or both of these samples; therefore, trends in redox and sludge ratio effects for the water soluble fraction are not discernable and the discussion will focus on the exchangeable and DTPA fractions, though all of the data is tabulated in Appendix A.

Except for Mn, there was generally an increase in exchangeable and DTPA-extractable levels of the elements studied with an increase in the sludge ratio. Also, except for Mn and Mo, the largest proportion of the elements was in the DTPA fraction. This was especially apparent as the sludge ratio increased, indicating the important role of high molecular weight organics in binding these elements in soils and sludge-amended soils.

Levels of exchangeable and DTPA extractable Cu, Zn, Cd, and Pb were generally much greater in oxidized sludge-soil suspensions than in reduced suspensions. Exchangeable and DTPA extractable levels of Fe, Mn, and P responded to redox potential conditions in the opposite manner. This was anticipated for Fe and Mn since these metals are subject to redox-mediated valence changes which make them much more chemically mobile under reducing conditions as ferrous Fe (Fe^{2+}) and manganous Mn (Mn^{2+}) (Gotoh and Patrick, 1974; Gotoh and Patrick, 1972). Also, P has been reported to be more available under reducing conditions than under oxidizing conditions (Patrick and Khalid, 1974). Phosphorus availability is thought to be influenced by Fe chemistry in soils.

This preliminary experiment indicated that: 1) the addition of metals with sludge increases metal levels in several chemical forms, but that the organic bound pool may be especially important, and 2) soil redox potential conditions affect levels of metals in various chemical forms. One implication of this is that soil redox conditions may affect plant availability of trace and toxic metals as well.

Figures 4 through 10 indicate how redox potential and sludge-soil ratios influenced the recovery of those elements that responded to soil oxidation conditions in the exchangeable and DTPA extractable forms (see Appendix A for complete tabulation of the data from Experiment A).

EXPERIMENT D: EFFECT OF AEROBIC OR ANAEROBIC SEWAGE DIGESTION ON CHEMICAL AVAILABILITY AND PLANT CONCENTRATION OF TRACE ELEMENTS

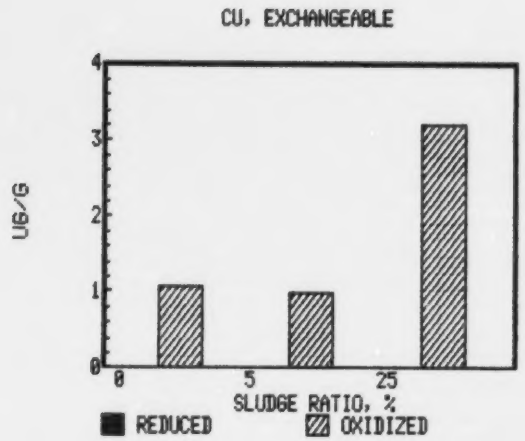
A study was conducted in which corn, rice, and soybeans were grown for a few weeks in a Loring silt loam soil material amended with 0, 1, 2, 3, and 5 percent sludge. Half of the experimental units received aerobically digested Baton Rouge sludge while the remainder received anaerobically digested sludge. The method of sewage digestion was the primary treatment since the objective was to determine if aerobic or anaerobic digestion of sludge affected the chemical mobility or plant availability of trace elements.

The concentrations of selected trace elements in humic, fulvic, and precipitate fractions extracted from the aerobically and anaerobically digested soil-sludge mixture are given in Table 4.

In general, there were very few, if any, significant treatment effects due in part to the relatively large variability (as indicated by standard deviations) between replicate samples. Also, this experiment would have been improved if the sewage material selected for digestion under aerobic and anaerobic conditions had contained a greater concentration of the trace and toxic elements of interest. Apparently, the sludge from the Baton Rouge Central Sewage Treatment Plant is less contaminated than many other municipal sludges.

Two trends were apparent. The levels of both zinc and copper in corn and rice shoots decreased with an increased sludge ratio. Despite higher total soil levels of these elements with increasing sludge ratios, the sludge-associated retention mechanisms (thought to be primarily organic matter) may have effectively immobilized added zinc and copper as well as some of the indigenous soil zinc and copper. Also, there was a very noticeable increase in the iron content of rice after the addition of sludge.

Table 5 gives an example of the results of this study with copper. Complete data for copper as well as other elements are given in Appendix D.



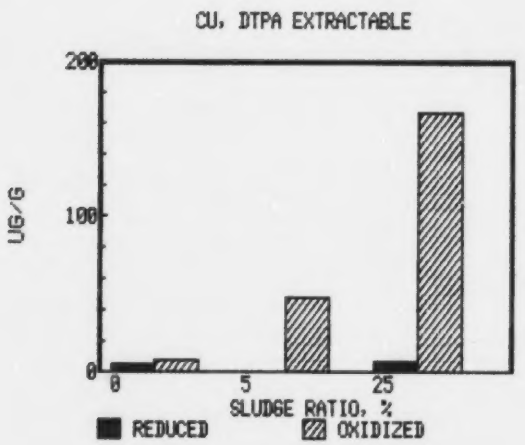
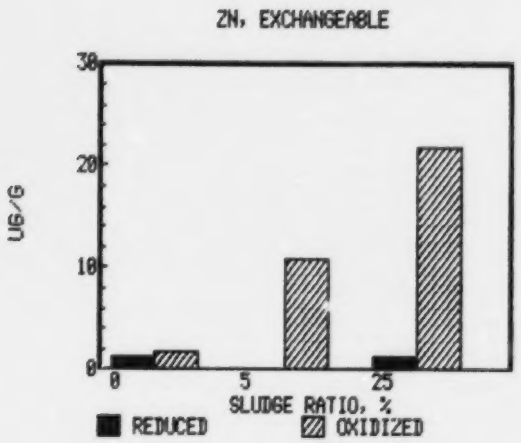


Figure 4. Effects of sludge ratio and oxidation conditions on extractable copper.



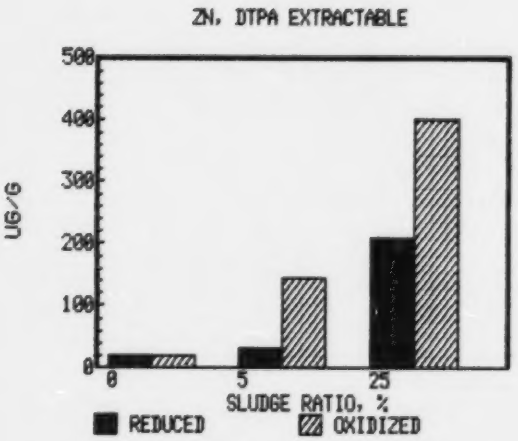


Figure 5. Effects of sludge ratio and oxidation conditions on extractable zinc.

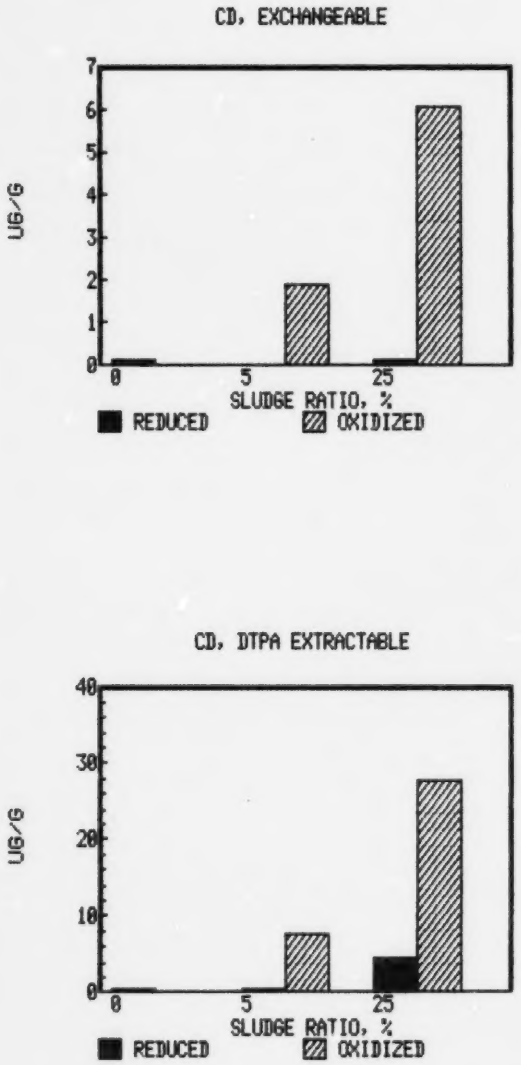


Figure 6. Effects of sludge ratio and oxidation conditions on extractable cadmium.

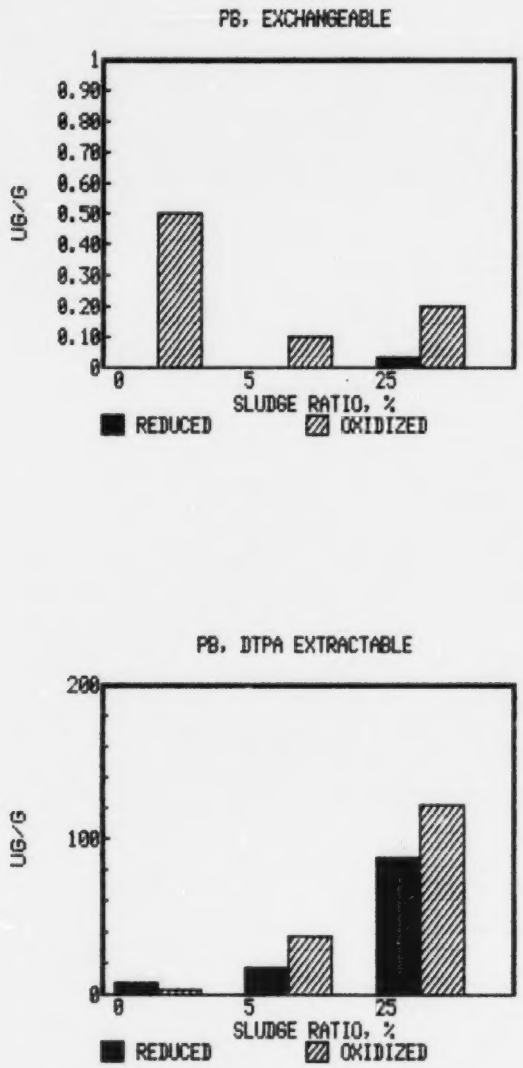
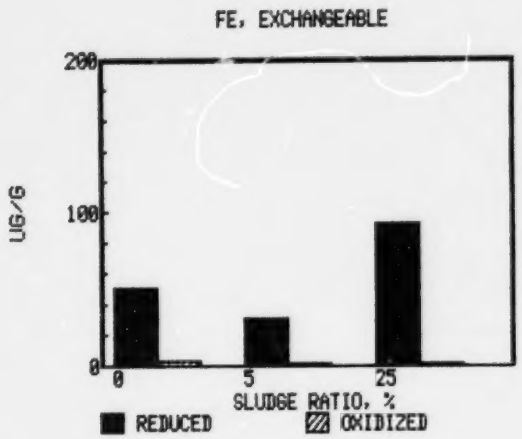


Figure 7. Effects of sludge ratio and oxidation conditions on extractable lead.



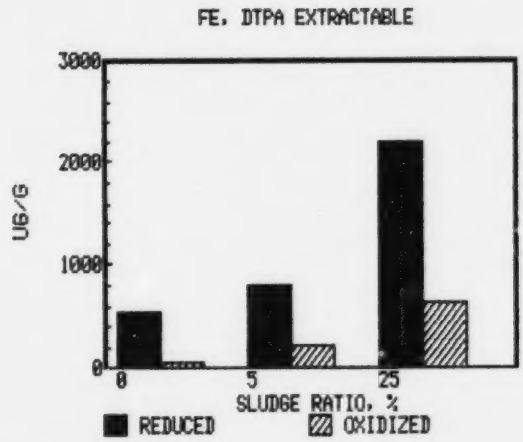


Figure 8. Effects of sludge ratio and oxidation conditions on extractable iron.

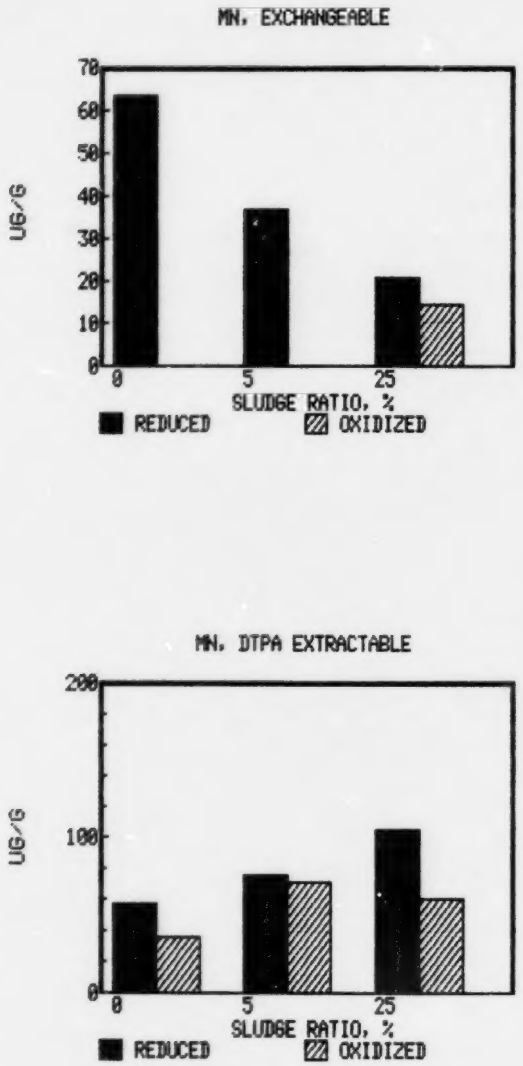
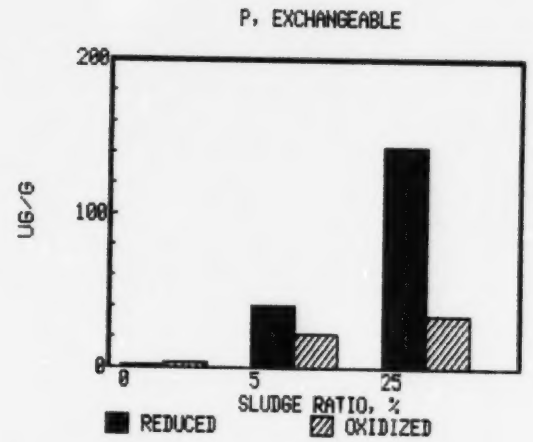


Figure 9. Effects of sludge ratio and oxidation conditions on extractable manganese.



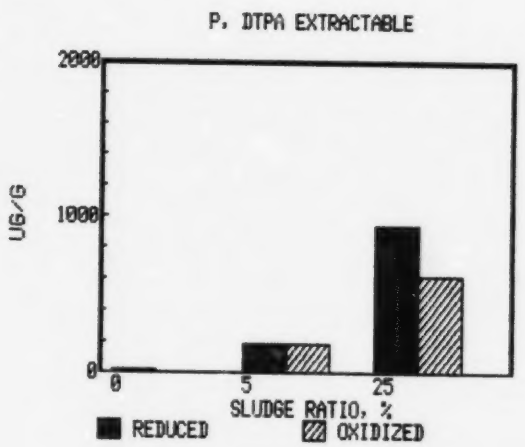


Figure 10. Effects of sludge ratio and oxidation conditions on extractable phosphorus.

TABLE 4. ELEMENTAL CONTENT OF HUMIC, FULVIC, AND PRECIPITATE (β-HUMUS) FRACTIONS EXTRACTED FROM THE AEROBICALLY AND ANAEROBICALLY DIGESTED BATON ROUGE SLUDGE

Form	Digestion Method	Cu	Zn	Cd	Pb	Cr	Ni	As	Fe	Mn	P	Al	PCT-FRAC
		μg/g											%
Fulvic	Anaerobic	14.57†	7.11	0.11	0.94	0.15	4.91	1.60	42.08	2.08	407.99	16.25	20.94
		—‡	—	—	—	—	—	—	—	—	—	—	—
Fulvic	Aerobic	—	—	—	—	—	—	—	—	—	—	—	—
		—	—	—	—	—	—	—	—	—	—	—	—
Humic	Anaerobic	12.91	18.58	0.08	4.84	0.88	0.68	3.43	32.53	0.33	278.35	70.34	6.00
		±1.34*	4.19	0.03	1.88	0.12	0.28	1.21	8.29	0.10	53.81	16.70	0.30
Humic	Aerobic	9.93	12.90	0.0	0.24	0.72	0.56	1.51	30.95	0.19	237.77	61.21	4.90
		±0.78	0.68	0.0	0.19	0.03	0.05	0.00	1.90	0.01	15.53	7.51	0.28
PPT	Anaerobic	0.51	51.14	0.07	11.83	2.27	0.71	15.97	284	4.75	2013	1382	2.46
		±0.29	0.49	0.00	0.64	0.05	0.05	0.21	61	0.11	25	28	0.05
PPT	Aerobic	1.44	37.64	0.08	10.34	1.68	0.84	17.64	279	3.99	2026	1527	1.96
		±0.27	3.64	0.00	2.07	0.46	0.21	2.69	50	0.37	304	225	0.01

†Mean of duplicate subsamples.

‡Data from one (or both) subsamples missing.

*Standard deviation.

TABLE 5. COPPER IN SELECTED CHEMICAL FORMS AND PLANT TISSUE FROM A LORING SOIL MATERIAL AMENDED WITH VARYING RATIOS OF AEROBICALLY AND ANAEROBICALLY DIGESTED SLUDGE

Chemical form/ plant species	Aerobically digested sludge ratio, %				Anaerobically digested sludge ratio, %				Means of sludge-amended treatments		
	1	2	3	5	1	2	3	5	Control	Aerobic	Anaerobic
	µg/g soil (or plant tissue)										
Soluble	0.38†	0.39	0.30	0.45	0.29	0.30	0.44	0.46	0.47	0.35	0.37
	0.15‡	0.19	0.13	0.62	0.29	0.22	0.17	0.19	0.21	0.33	0.22
	6*	6	6	6	6	6	6	6	6	24	24
Exchangeable	0.26	0.18	0.22	0.17	0.36	0.21	0.19	0.34	0.25	0.20	0.27
	0.12	0.04	0.16	0.13	0.20	0.19	0.14	0.22	0.24	0.12	0.19
	6	6	6	6	6	6	6	6	4	24	24
DTPA Extractable	2.12	2.25	2.53	1.98	2.07	2.19	2.71	2.39	2.31	2.22	2.34
	0.88	1.39	1.79	2.10	1.28	1.56	1.99	2.50	0.32	1.51	1.78
	6	6	6	6	6	6	6	6	3	24	24
Corn	19.3	13.2	12.5	11.5	22.4	18.2	14.7	18.1	21.4	14.1	18.4
	4.0	2.9	1.7	5.0	8.0	4.3	3.5	3.2	2.8	4.2	4.8
	2	2	2	2	2	2	2	2	2	8	8
Rice	31.0	16.5	14.1	13.4	20.2	22.5	13.3	12.8	42.4	18.8	17.2
	1.1	0.4	0.4	3.4	2.3	8.5	3.0	0.7	1.7	7.8	5.8
	2	2	2	2	2	2	2	2	2	8	8
Soybeans	23.5	15.1	17.2	25.7	14.33	15.49	16.11	18.18	36.7	20.4	16.0
	10.7	0.6	0.0	14.9	1.15	2.26	0.72	1.54	—	8.4	1.9
	2	2	2	2	2	2	2	2	1	8	8

†Mean.

‡Standard deviation.

*Number of experimental units in sample (replicate samples for each of the plant species were extracted giving N = 6 for Soluble, Exchangeable, and DTPA Extractable Means.

To remove variability due to the use of different sludge-soil ratios and detect possible sludge digestion treatment effects, the Duncan's Multiple Range Test was applied to results of experimental units which received only a 3 percent amendment of aerobically or anaerobically digested Baton Rouge sludge. An analysis of variance procedure revealed that of the 15 elements measured in each of three plant species, only soybean levels of Cd and Fe were significantly different at the 5% testing level where more of each element was present in soybeans grown in the soil amended with the aerobically digested sludge. Upon examination of the data, it was decided to set up a similar experiment using only one sludge-soil ratio and greater replication (N = 5) to test for possible effects of the method of sludge digestion on plant content of selected metals (See Experiment N).

EXPERIMENT N: THE EFFECT OF AEROBIC AND ANAEROBIC DIGESTION OF BATON ROUGE SEWAGE ON THE CONCENTRATION OF SELECTED ELEMENTS IN CORN AND SOYBEAN PLANTS GROWN ON A 5 PERCENT SLUDGE-AMENDED DRUMMER SOIL MATERIAL

A study similar to Experiment D was conducted with the difference that only one sludge ratio and a greater number of replicates were used to examine whether or not the method of sewage digestion (aerobic vs. anaerobic) affected the plant availability of selected trace and toxic elements as indicated by plant concentration of these elements after short-term uptake studies. The results for selected potentially toxic elements are given in Table 6. In soybeans grown for 3 weeks in the 5

TABLE 6. CONCENTRATION OF SELECTED ELEMENTS IN CORN AND SOYBEANS GROWN IN A 5 PERCENT AEROBICALLY AND ANAEROBICALLY DIGESTED BATON ROUGE SLUDGE/DRUMMER SOIL MIXTURE

Plant	Digestion treatment	Mean metal concentration, ppm (N = 5)						
		Cu	Zn	Cd	Pb	Cr	Ni	As
Soybean	Control (0%)	12.9a*	67.5a	0.17a	0.07a	0.64a	6.79a	0.01a
Soybean	Anaerobic (5%)	13.7a	75.6a	0.14a	0.01a	0.56a	5.71a	0.08a
Soybean	Aerobic (5%)	12.7a	75.4a	0.16a	0.06a	0.69a	7.31a	0.16a
Corn	Control (0%)	14.7a	147a	0.10a	0.16a	4.76a	1.31a	0.00a
Corn	Anaerobic (5%)	20.8b	154a	0.45b	2.10b	8.13b	1.40a	0.52b
Corn	Aerobic (5%)	15.6a	135a	0.47b	0.93a	6.33ab	3.99a	0.37ab

*Means followed by the same letter within a plant/metal combination are not significantly different at the 5% level using Duncan's Multiple Range Test.

percent-amended Drummer soil, there was no indication the addition of sludge or the digestion method had an effect on the aboveground plant tissue content of Cu, Zn, Cd, Pb, Cr, Ni, or As. For corn, the plants

grown in the soil amended with 5 percent anaerobically digested sludge contained significantly more Cu, Cd, Pb, Cr, and As than the control plants. Pertaining to the method of digestion, significant differences were obtained only for Cu and Pb levels which were higher for both elements from the sludge which was derived from an anaerobic digestion process.

The data are given in Appendix N for Fe, Mn, Ca, Mg, Mo, Si, P, and Al.

EXPERIMENT G: TRACE AND TOXIC METALS IN HUMIC AND FULVIC ACIDS

For most of the metal chemical availability studies conducted, humic and fulvic acids and a precipitate fraction were extracted from the sludge-soil mixtures and analyzed for trace and toxic metals to determine treatment (pH and redox potential) effects on the association of metals with sludge and soil organic matter. The results of these studies are presented in the following paragraphs.

Metals in Humic Acid Fractions of Aerobically and Anaerobically Digested Baton Rouge Sludge

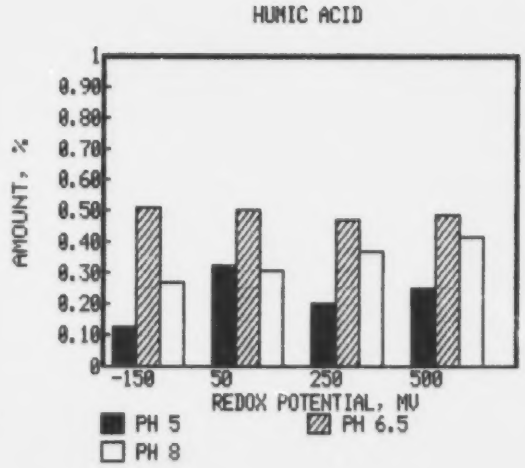
Table 4, Experiment D, indicates the levels of selected elements in samples of sludge derived from aerobic or anaerobic digestion of sewage from the Baton Rouge Central Sewage Treatment Plant. Data are missing from the oxidized fulvic acid fraction because these samples could not be dried to obtain sample weights. Also, one subsample of the reduced fulvic acid fraction was lost. These data are summarized in the discussion for Experiment G.

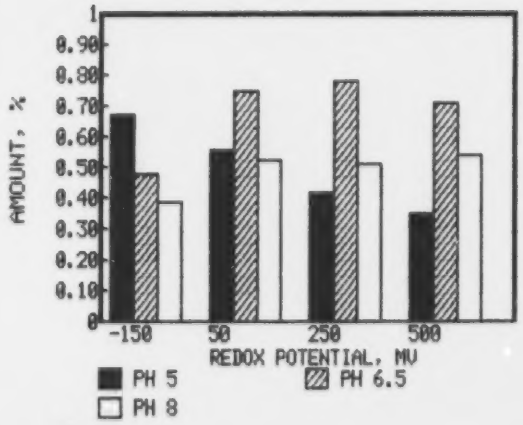
Effect of Controlled pH and Redox Potential Conditions on the Association of Selected Elements with the Humic, Fulvic, and Precipitate Fractions from the Drummer Soil/Chicago Reference Sludge Mixture

Following the incubations of sludge-soil mixtures under controlled pH and redox potential conditions, aliquots of the suspension were taken for extraction of humic and fulvic acids as well as a precipitate fraction. The precipitate ("β-humus") fraction is thought to be predominantly metal precipitates with entrapped organic matter (Holtzclaw et al., 1978). The values reported are of selected elements per gram of designated fraction on an oven-dry solids basis.

Figure 11 indicates the proportion of each sample extracted as humic and fulvic acids and the precipitate fraction. Fulvic acid was apparently recovered in the greatest amount, though it should be noted a substantial part of this fraction is composed of extracting reagents (primarily sodium). The elements examined included Cu, Zn, Cd, Pb, Cr, Ni, As, Fe, Mn, Mo, P, and Al.

In terms of relative concentration in the various fractions, Cu, Zn, and Ni were strongly associated with the fulvic acid fraction compared to concentrations in the other two forms. However, it should be noted that





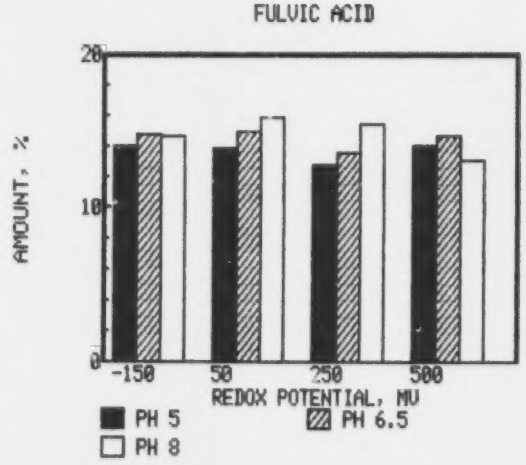


Figure 11. Effect of pH and Eh conditions on extractable humic materials.

the much greater quantity of fulvic acid extracted relative to the other two forms would result in a greater total quantity of most elements of interest being in this fraction than in the humic and precipitate forms. Copper was also present in about equal concentration in the humic acid fraction. The concentration of all other elements in the humic acid fraction was either about the same as or less than levels in the fulvic and precipitate forms.

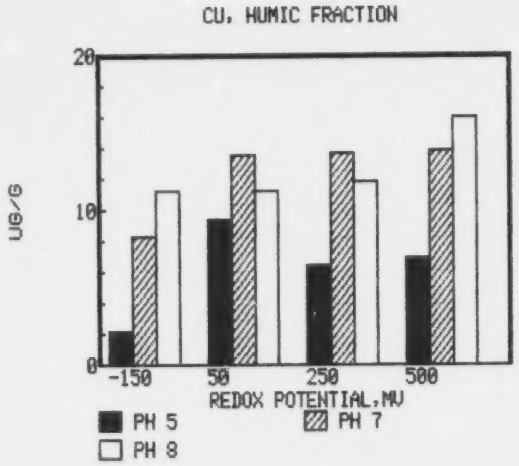
There were no consistent, unidirectional changes in concentration with increasing pH and redox potential for any element examined in any of the three fractions. However, levels of Cu were generally lower in all three fractions under strongly reducing conditions (-150 mv) than in better oxidized treatments at pH levels of 5.0 and 6.5 (Figure 12). At pH 5.0, Zn levels tended to decrease with increasing redox potential (Figure 13). Undetectable to very low levels of Cd were recovered in the humic and precipitate fractions. Cadmium levels in the fulvic acid fraction generally increased with increasing redox potential levels (Figure 14).

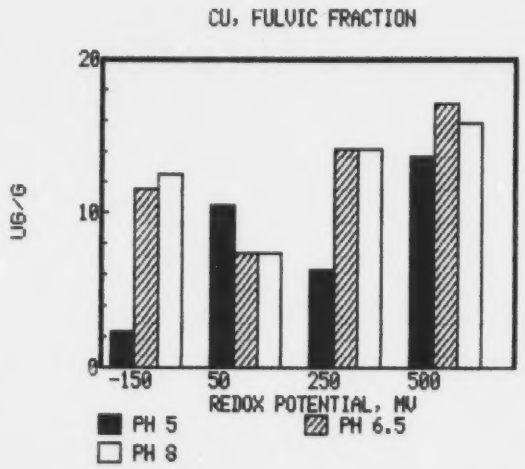
EXPERIMENT C, E, F, I, J, K, L, AND M: EFFECT OF REDOX POTENTIAL AND pH ON THE CHEMICAL AVAILABILITY OF SELECTED ELEMENTS

Mixtures of Chicago reference sludge and Drummer soil material were incubated as suspensions under controlled pH (5.0, 6.5, and 8.0) and redox potential (-150, 50, 250, and 500 millivolts) conditions where -150 millivolts represents strongly reducing (anaerobic) conditions and 500 millivolts represents well oxidized (aerobic) soil conditions. Similar studies were done with a Loring silt loam soil material amended with anaerobically digested Baton Rouge sludge. Where means and standard deviations were reported for chemical availability studies, duplicate subsamples were removed from the experimental suspensions and extracted separately in the chemical fractionation procedure. These procedures do not represent true replication, but do indicate levels of variability associated with sampling, sample processing, and analysis. For purposes of comparing with other chemical forms, levels of dissolved metals were reported as micrograms of metal in the aqueous phase divided by the number of grams of oven dry soil solids in the sampled aliquot.

For purposes of evaluating the results of the chemical availability studies, the discussion will focus on data from Experiments J, I, and K (pH 5.0, 7.0, 8.0, Chicago reference sludge/Drummer soil). Although the sludge and soil mixtures and treatments of the E, C, and F series were similar, the J, I, and K series was selected for detailed discussion since the experimental techniques were slightly improved by this time and an additional extraction procedure (H_2O_2 digestion) was incorporated into the chemical fractionation scheme, providing important information on the residual organic bound phase.

Data for all studies are presented in the appendix tables.





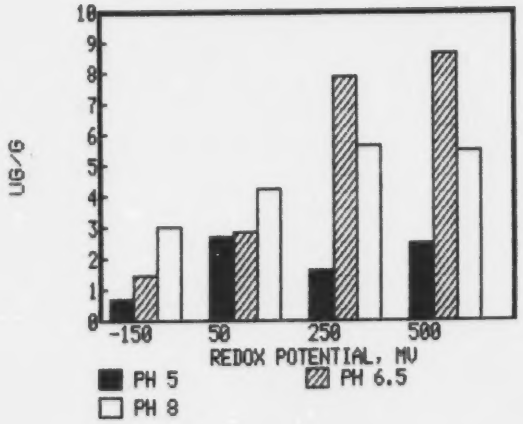
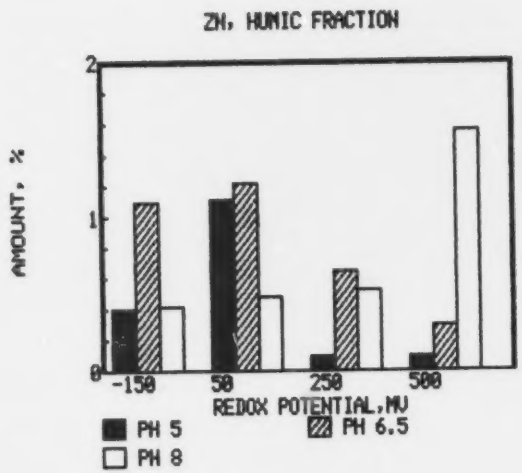
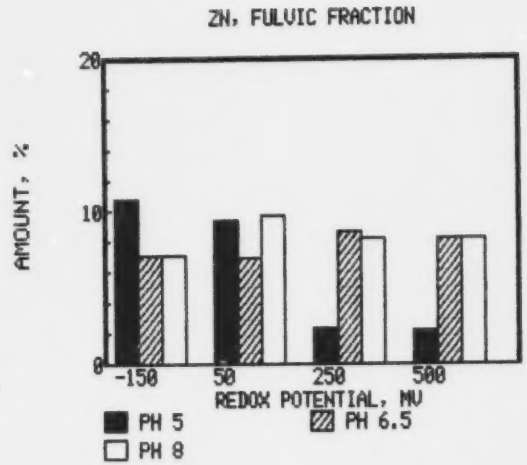


Figure 12. Effect of pH and Eh conditions on Cu levels in humic materials.





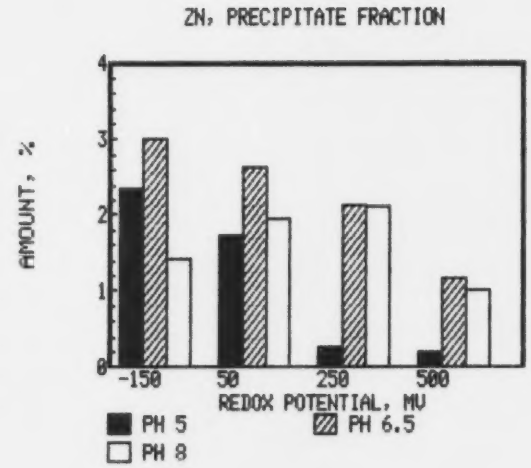
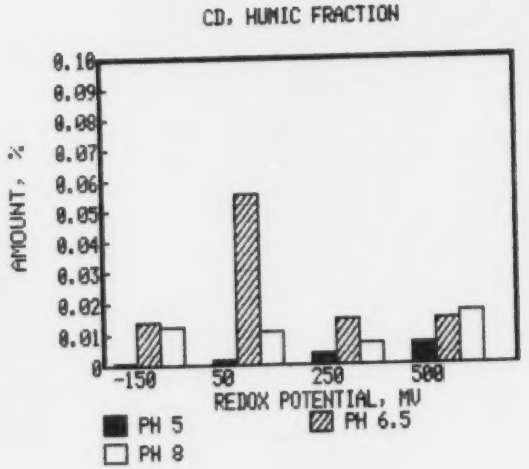
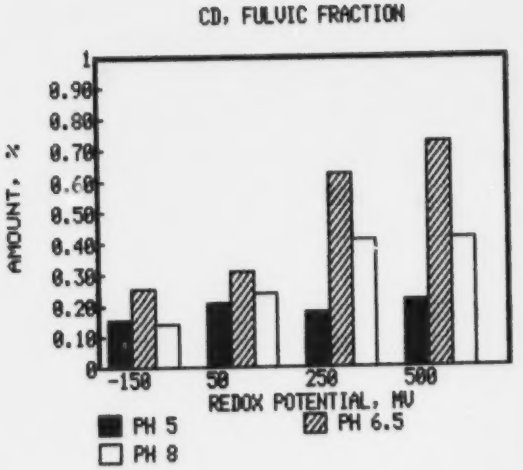


Figure 13. Effect of pH and Eh conditions on Zn levels in humic materials.





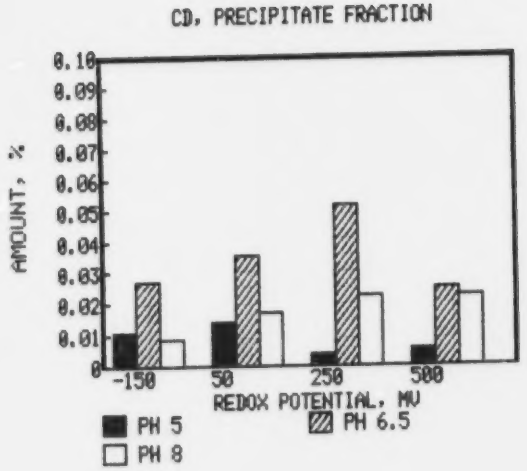


Figure 14. Effect of pH and Eh conditions on Cd levels in humic materials.

Copper

Table 7 presents data on the effect of pH and redox potential on levels of Cu in the various chemical forms. There was a trend toward an increase of Cu in the dissolved, exchangeable, and DTPA extractable forms with increasing redox potential. Dissolved and exchangeable Cu represent the most readily available forms, while the DTPA form likely represents potentially available Cu that is held to soil organics by retention mechanisms intermediate in strength between the exchangeable form and the H_2O_2 digestible form. The bonding strength of this type of organic matter association apparently gets weaker with increasing redox potential, as indicated by the greater recovery of DTPA extractable Cu under oxidized conditions. One of the most striking aspects of Cu forms and transformations in soils and sediments under different oxidation conditions is the sequential increase in reducible (believed to be associated with hydrous iron oxides) copper levels with increasing redox potential. Reducible Cu accounts for most of the potentially available Cu under oxidizing conditions. The residual organic bound (H_2O_2 digestible) Cu decreases sequentially with increasing oxidation conditions. (Under strongly reducing conditions such as -150 millivolts where some sulfide is present, the H_2O_2 digestion will also recover metals precipitated as insoluble sulfides). This is because more of the potentially available Cu is recovered by the less rigorous, early extraction procedures in the sequential chemical fractionation scheme. It is apparent from these data that the organic (+ sulfide) form of Cu predominates under reducing conditions, and that a large proportion of this potentially available Cu is transformed to a predominately mineral form (reducible) under oxidizing conditions. Although relatively large quantities of Cu are moving between the potentially available forms as redox potential changes, relatively small shifts occur in the amounts of readily available soluble and exchangeable forms. Figure 15 summarizes the effect of redox potential at pH 8.0.

Zinc

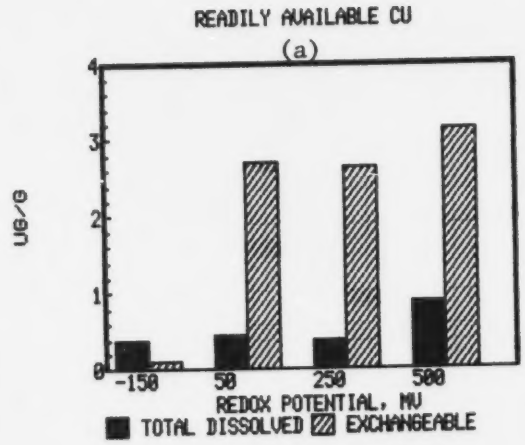
Dissolved and exchangeable Zn levels were much greater at pH 5.0 than at the two higher pH levels. This is in accord with the commonly observed effects of pH on Zn mobility and plant availability as reported in the literature. There was a weak trend for readily available Zn to increase with increasing redox potential at the lower pH levels in contrast to very large increases in plant Zn content with increasing redox potential (plant data will be presented elsewhere). The Baton Rouge sludge/Loring soil gave opposite results for dissolved and exchangeable Zn levels.

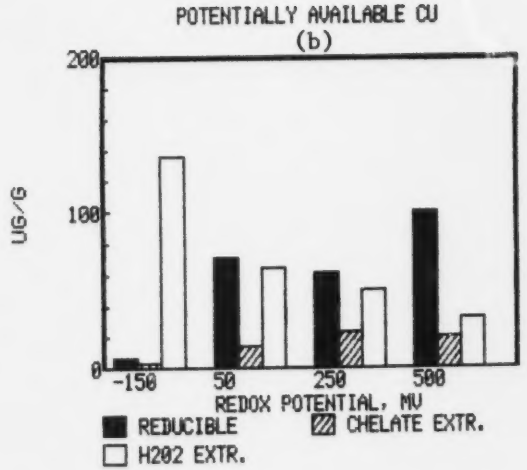
Most of the total potentially available Zn present was in the reducible form with the residual organic bound (H_2O_2 digestible) and DTPA extractable levels removing approximately one-half and one-fourth the reducible levels respectively (Table 8, Figure 16).

Table 7: The Effects of pH and Redox Potential on Levels of Copper in Selected Chemical Forms in a Drummer Soil/Chicago Reference Sludge Material.

pH	Form	Redox Potential, mv			
		-150	50	250	500
		ug/g, oven dry solids basis			
5.0	Total Dissolved[1]	m[2]	0.35[3]	0.55	0.55
	Exchangeable	m	0.0	3.15	3.55
	Reducible	m	3.30	102.0	75.6
	DTPA Extractable	m	3.50	19.6	22.6
	H2O2 Extractable	m	119.0	32.0	28.0
6.5	Total Dissolved	0.10	0.05	0.10	0.25
	Exchangeable	2.90	0.70	1.90	2.45
	Reducible	1.05	29.4	91.0	112.0
	DTPA Extractable	3.40	12.0	19.7	19.0
	H2O2 Extractable	m	m	m	m
8.0	Total Dissolved	0.40	0.45	0.40	0.90
	Exchangeable	0.10	2.70	2.65	3.15
	Reducible	7.15	71.5	61.8	101.0
	DTPA Extractable	4.10	15.05	23.6	20.4
	H2O2 Extractable	136.0	64.7	52.2	32.9

[1] total dissolved expressed as ug/g oven dry solids basis where water to solids ratio was 5:1 (w/w).
[2] missing value.
[3] mean of duplicate subsamples.





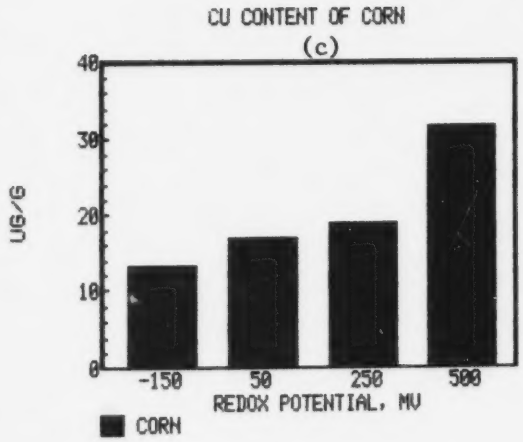
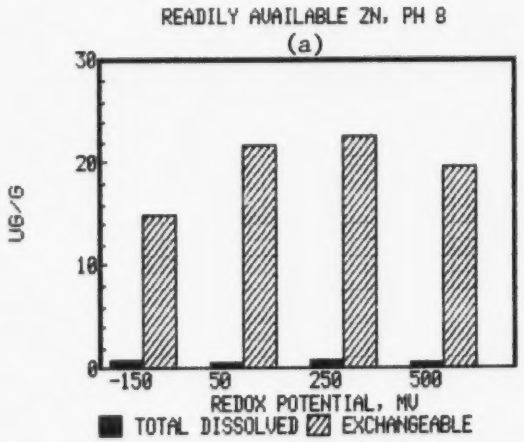


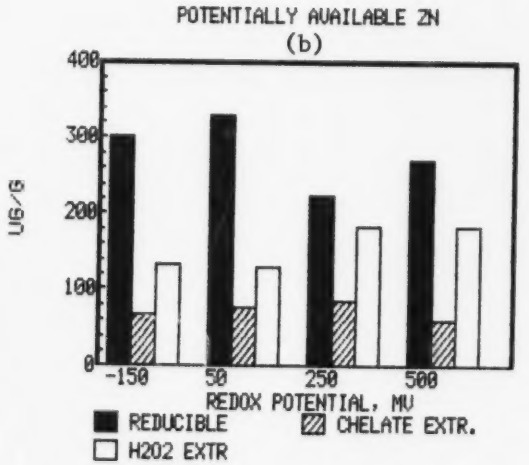
Figure 15. The effect of soil redox potential at pH 8 on levels of copper in readily available (a) and potentially available (b) chemical forms in a Drummer soil/ Chicago reference sludge mixture and in corn plants (c) grown in this mixture.

Table 8: The Effects of pH and Redox Potential on Levels of Zinc in Selected Chemical Forms in a Drummer Soil/Chicago Reference Sludge Material.

pH	Form	Redox Potential, mv			
		-150	50	250	500
		ug/g, oven dry solids basis			
5.0	Total Dissolved[1]	m[2]	34.4[3]	42.4	41.6
	Exchangeable	m	121.0	116.0	111.0
	Reducible	m	220.0	232.0	200.0
	DTPA Extractable	m	61.2	45.8	48.8
	H2O2 Extractable	m	110.0	120.0	118.0
6.5	Total Dissolved	0.40	0.80	1.35	1.50
	Exchangeable	0.90	12.4	18.5	21.0
	Reducible	308.0	316.0	266.0	283.0
	DTPA Extractable	93.6	75.7	58.1	54.0
	H2O2 Extractable	m	m	m	m
8.0	Total Dissolved	0.75	0.60	0.75	0.50
	Exchangeable	14.9	21.8	22.6	20.0
	Reducible	303.0	329.0	224.0	269.0
	DTPA Extractable	67.2	77.8	84.6	60.0
	H2O2 Extractable	132.0	130.0	182.0	183.0

[1] total dissolved expressed as ug/g oven dry solids basis where water to solids ratio was 5:1 (w/w).
[2] missing value.
[3] mean of duplicate subsamples.





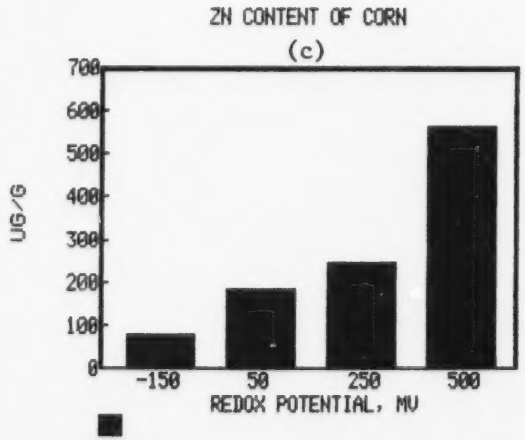


Figure 16. The effect of soil redox potential at pH 8 on levels of zinc in readily available (a) and potentially available (b) chemical forms in a Drummer soil/Chicago reference sludge mixture and in corn plants (c) grown in this mixture.

Cadmium

As will be discussed elsewhere, the Cd levels in plant tissue, like Zn, increased greatly with increasing redox potential levels at all pH levels. Levels of dissolved and exchangeable Cd responded similarly only at pH 6.5. In proportion to the total amount of potentially available Cd present, a much larger fraction was recovered in the dissolved and exchangeable forms compared to most other trace and toxic metals studied. This is also reflected in the high concentrations which can be accumulated in plants grown on cadmium-contaminated soils.

In comparison to most other trace and toxic metals examined in this study, cadmium appears to be less strongly associated with organics and particularly weakly bound by iron hydrous oxides (reducible phase). In other studies designed to specifically examine this association, Kinniburgh, Sridhar, and Jackson (1977) also found Cd is weakly bound to iron hydrous oxides compared to other metals. Thus, this research supports other studies which indicate that cadmium contamination of soils and sediments represents a greater environmental risk than many other toxic metals at equivalent levels because of its relatively high mobility. Cadmium results are indicated in Table 9, Figure 17.

Lead

Exchangeable Pb levels were very pH-dependent; the highest values were found at pH 5.0 Exchangeable Pb was little affected by redox potential. Gambrell, Khalid, and Patrick (1980) observed similar physicochemical effects on exchangeable lead in dredged sediments. The largest concentration of potentially available Pb was in the residual organic bound (H_2O_2 digestible) fraction with reducible and DTPA extractable levels both ranging between about 10 and 20 percent of the residual organic levels. With the exception of the pH effect on exchangeable lead, changing pH and redox potential levels had little noticeable effect on concentrations in the other chemical forms of lead (Table 10, Figure 18).

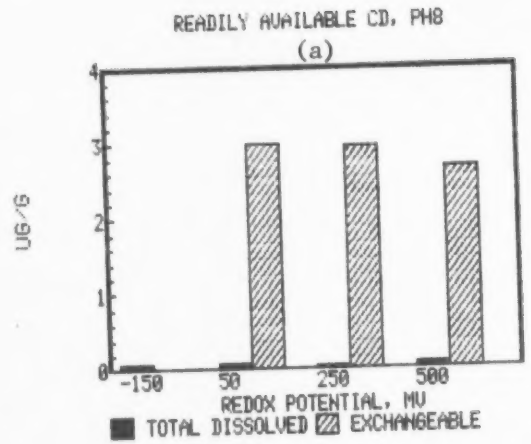
Chromium

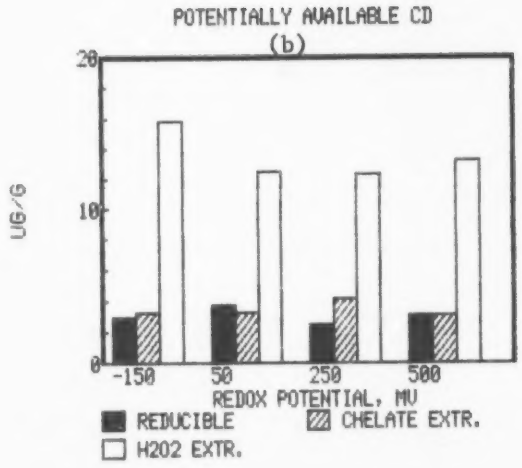
An examination of all of the chemical availability data showed no effect of either pH or redox potential on total Cr in the dissolved, exchangeable, reducible, DTPA extractable, or residual organic bound forms (Table 11, Figure 19). The highest level of potentially available Cr was found in the residual organic bound fraction, with reducible Cr levels about one-half to two-thirds as great. DTPA extractable levels ranged from about 15 to 25 parts per million. Both dissolved and exchangeable Cr levels were generally less than 0.5 part per million, except for the pH 6.5/rice study in which the comparatively high means and high standard deviations indicate contamination of one subsample.

Table 9: The Effects of pH and Redox Potential on Levels of Cadmium in Selected Chemical Forms in a Drummer Soil/Chicago Reference Sludge Material.

		Redox Potential, mv			
pH	Form	-150	50	250	500
		ug/g, oven dry solids basis			
5.0	Total Dissolved[1]	m[2]	1.59[3]	2.28	2.08
	Exchangeable	m	7.27	7.50	7.48
	Reducible	m	2.40	3.53	2.69
	DTPA Extractable	m	2.37	3.16	3.09
	H2O2 Extractable	m	8.30	7.10	6.70
6.5	Total Dissolved	0.01	0.08	0.12	0.13
	Exchangeable	0.0	2.96	3.52	3.96
	Reducible	0.42	3.14	3.26	3.11
	DTPA Extractable	1.66	2.16	2.88	2.23
	H2O2 Extractable	m	m	m	m
8.0	Total Dissolved	0.08	0.08	0.06	0.06
	Exchangeable	0.02	2.97	2.94	2.66
	Reducible	2.95	3.70	2.52	3.22
	DTPA Extractable	3.26	3.31	4.20	3.17
	H2O2 Extractable	15.8	12.5	12.4	13.2

[1] total dissolved expressed as ug/g oven dry solids basis where water to solids ratio was 5:1 (w/w).
[2] missing value.
[3] mean of duplicate subsamples.





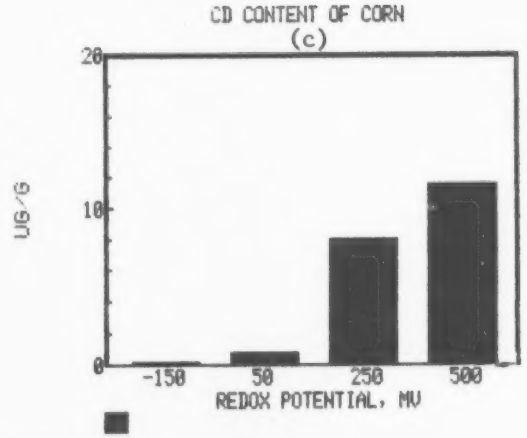
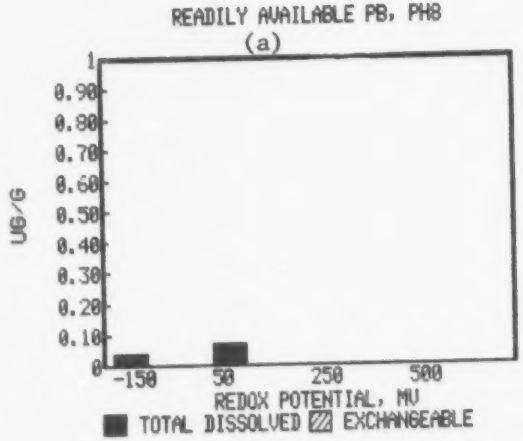


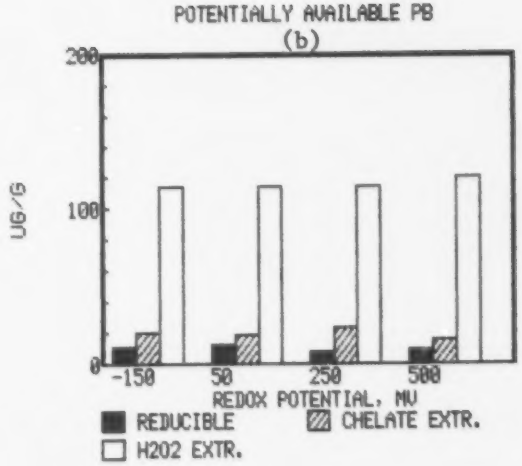
Figure 17. The effect of soil redox potential at pH 8 on levels of cadmium in readily available (a) and potentially available (b) chemical forms in a Drummer soil/Chicago reference sludge mixture and in corn plants (c) grown in this mixture.

Table 10: The Effects of pH and Redox Potential on Levels of Lead in Selected Chemical Forms in a Drummer Soil/Chicago Reference Sludge Material.

pH	Form	Redox Potential, mv			
		-150	50	250	500
		ug/g, oven dry solids basis			
5.0	Total Dissolved[1]	m[2]	0.53[3]	0.06	0.02
	Exchangeable	m	4.13	0.62	0.92
	Reducible	m	11.3	20.7	10.4
	DTPA Extractable	m	18.0	24.1	23.9
	H2O2 Extractable	m	102.0	94.6	93.8
6.5	Total Dissolved	0.10	0.0	0.0	0.0
	Exchangeable	0.05	0.26	0.12	0.08
	Reducible	18.3	24.8	22.5	25.5
	DTPA Extractable	20.1	15.2	17.7	16.6
	H2O2 Extractable	m	m	m	m
8.0	Total Dissolved	0.04	0.07	0.0	0.0
	Exchangeable	0.0	0.0	0.0	0.0
	Reducible	11.8	13.7	7.8	10.2
	DTPA Extractable	20.0	18.6	23.2	15.9
	H2O2 Extractable	115.0	114.0	115.0	121.0

[1] total dissolved expressed as ug/g oven dry solids basis where water to solids ratio was 5:1 (w/w).
[2] missing value.
[3] mean of duplicate subsamples.





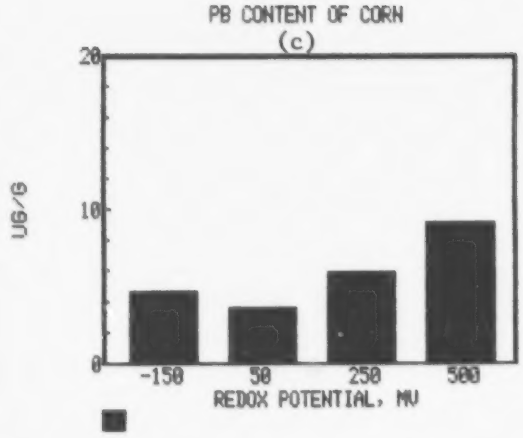
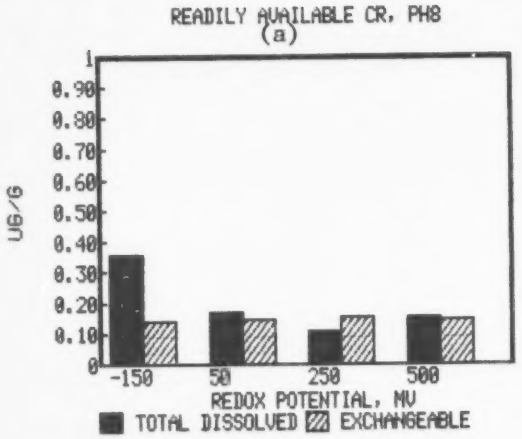


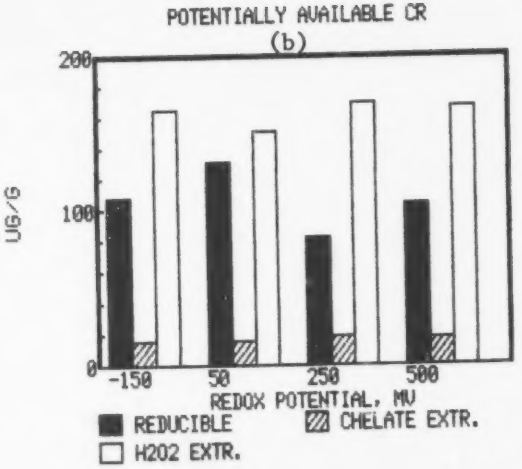
Figure 18. The effect of soil redox potential at pH 8 on levels of lead in readily available (a) and potentially available (b) chemical forms in a Drummer soil/Chicago reference sludge mixture and in corn plants (c) grown in this mixture.

Table 11: The Effects of pH and Redox Potential on Levels of Chromium in Selected Chemical Forms in a Drummer Soil/Chicago Reference Sludge Material.

		Redox Potential, mv			
pH	Form	-150	50	250	500
		ug/g, oven dry solids basis			
5.0	Total Dissolved[1]	m[2]	0.32[3]	0.28	0.28
	Exchangeable	m	0.28	0.21	0.26
	Reducible	m	104.0	115.1	63.6
	DTPA Extractable	m	16.9	17.3	20.8
	H202 Extractable	m	145.0	162.0	152.0
6.5	Total Dissolved	0.14	0.09	0.08	0.10
	Exchangeable	0.18	0.15	0.15	0.16
	Reducible	130.0	122.0	118.0	127.0
	DTPA Extractable	24.3	21.8	23.9	22.8
	H202 Extractable	m	m	m	m
8.0	Total Dissolved	0.36	0.17	0.11	0.16
	Exchangeable	0.14	0.15	0.16	0.15
	Reducible	109.0	131.0	82.4	104.0
	DTPA Extractable	16.6	16.4	19.8	17.4
	H202 Extractable	166.0	151.0	170.0	167.0

[1] total dissolved expressed as ug/g oven dry solids basis where water to solids ratio was 5:1 (w/w).
[2] missing value.
[3] mean of duplicate subsamples.





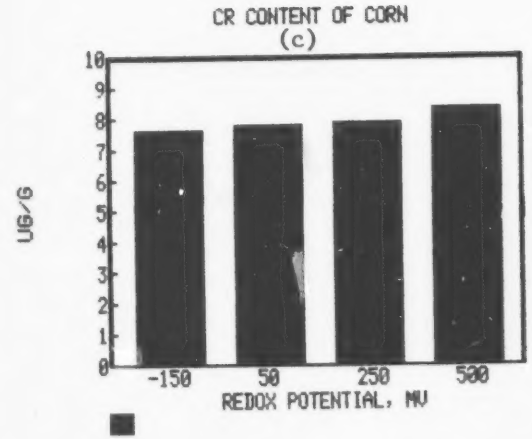


Figure 19. The effect of soil redox potential at pH 8 on levels of chromium in readily available (a) and potentially available (b) chemical forms in a Drummer soil/Chicago reference sludge mixture and in corn plants (c) grown in this mixture.

Nickel

There was a small but consistent decline in levels of dissolved Ni with increasing redox potentials in all pH treatments. There was also a decrease in exchangeable and especially dissolved Ni as pH increased from 5.0 to 6.5 and 8.0. Dissolved Ni decreased from around 5 parts per million (soil solids basis) at pH 5.0 to around 1 or less at pH 8.0. The largest concentration of potentially available Ni was in the reducible fraction (25 to 50 parts per million). Where measured, the residual organic bound levels were just less than reducible levels (20 to 30 parts per million) and DTPA extractable levels ranged between 6 and 10 parts per million (Table 12, Figure 20).

Arsenic

Dissolved As generally decreased with increasing redox potential measurements. Where an H_2O_2 digestion was done, As levels were greatest in this form, about 20 times higher than in the DTPA extractable phase (Table 13, Figure 21).

Other Elements

The chemical availability data for Fe, Mn, Ca, Mg, Mo, Si, P, and Al are available in the appendix tables, but will not be summarized here as this report is primarily concerned with toxic and potentially toxic elements.

EXPERIMENTS C, E, I, J, K, L, AND M: EFFECT OF REDOX POTENTIAL ON PLANT CONCENTRATIONS OF SELECTED ELEMENTS IN SLUDGE-AMENDED SOILS

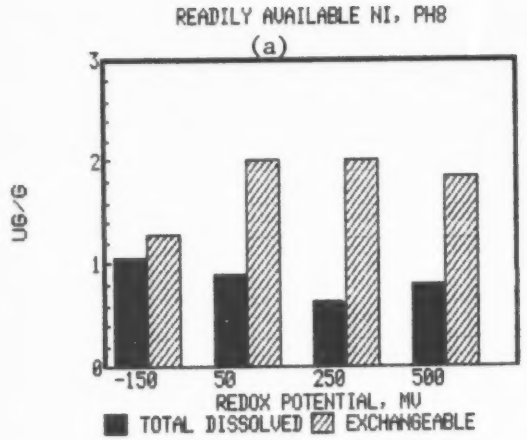
After sludge-soil suspension aliquots were withdrawn for chemical availability studies, either rice or corn seedlings were transplanted into the suspensions and grown for a two-week period. Several attempts to grow soybeans in the laboratory microcosms were unsuccessful. Plant material from each experimental unit was harvested in two batches, which were digested and analyzed separately. Complete elemental data were obtained from Experiment C (pH 6.5, rice), partial data for elemental levels in rice for Experiment E (pH 5.0), and data are unavailable for rice at pH 8.0 (Experiment F). Tables 14 and 15 give the mean elemental concentration and standard deviation for subsamples of rice and corn seedlings grown for two week periods under controlled pH and redox potential conditions.

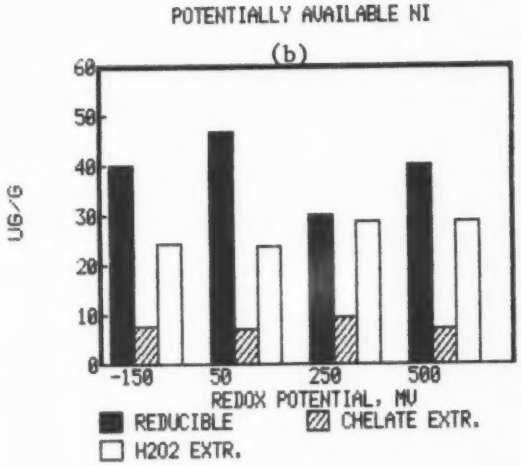
These plant uptake studies were intended to indicate relative treatment effects of varying soil physicochemical conditions on plant availability of selected trace and toxic elements. It would be difficult to compare the plant concentration data obtained with other plant concentration data in the literature because of the short (2 week) growing period and because the plants were harvested at a very early age. Also, there were slight age differences between the plants used in different experiments and some variability in the length of time the sludge-soil suspensions were incubated

Table 12: The Effects of pH and Redox Potential on Levels of Nickel in Selected Chemical Forms in a Drummer Soil/Chicago Reference Sludge Material.

pH	Form	Redox Potential, mv -150	50	250	500
		ug/g, oven dry solids basis			
5.0	Total Dissolved[1]	m[2]	6.70[3]	5.05	4.95
	Exchangeable	m	11.0	8.90	8.80
	Reducible	m	30.6	35.0	27.2
	DTPA Extractable	m	6.25	6.30	7.25
	H2O2 Extractable	m	21.5	22.5	22.0
6.5	Total Dissolved	1.10	0.70	0.60	0.70
	Exchangeable	2.30	1.10	1.90	2.20
	Reducible	43.1	43.6	39.8	41.7
	DTPA Extractable	10.2	8.65	7.20	6.55
	H2O2 Extractable	m	m	m	m
8.0	Total Dissolved	1.05	0.90	0.65	0.80
	Exchangeable	1.30	2.00	2.00	1.85
	Reducible	40.4	47.0	30.4	40.2
	DTPA Extractable	7.80	7.60	9.60	7.50
	H2O2 Extractable	24.4	23.9	28.6	28.6

[1] total dissolved expressed as ug/g oven dry solids basis where water to solids ratio was 5:1 (w/w).
[2] missing value.
[3] mean of duplicate subsamples.





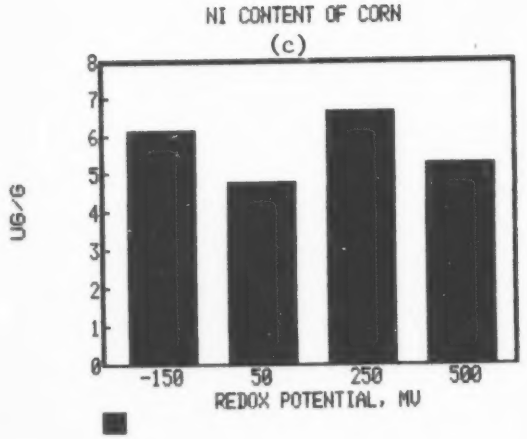
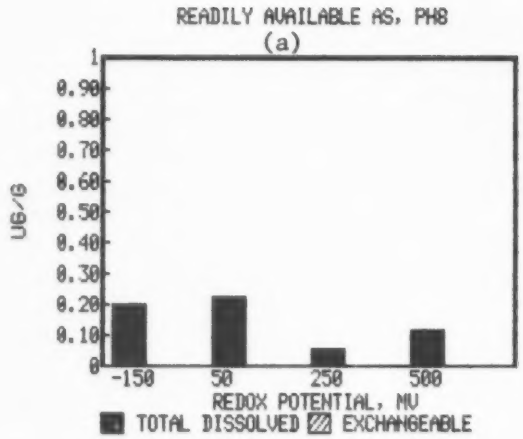


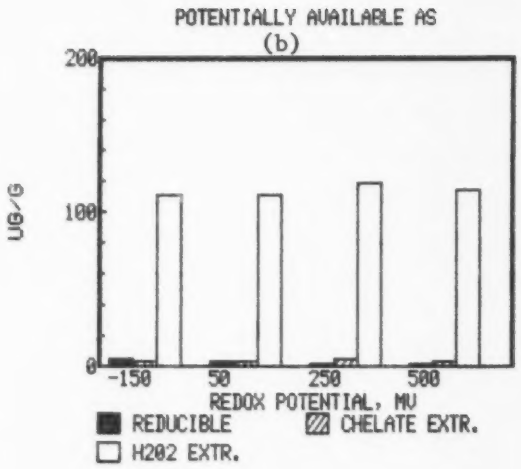
Figure 20. The effect of soil redox potential at pH 8 on levels of nickel in readily available (a) and potentially available (b) chemical forms in a Drummer soil/Chicago reference sludge mixture and in corn plants (c) grown in this mixture.

Table 13: The Effects of pH and Redox Potential on Levels of Arsenic in Selected Chemical Forms in a Drummer Soil/Chicago Reference Sludge Material.

pH	Form	Redox Potential, mv			
		-150	50	250	500
		ug/g, oven dry solids basis			
5.0	Total Dissolved[1]	m[2]	1.44[3]	0.15	0.0
	Exchangeable	m	0.0	0.0	0.0
	Reducible	m	3.44	2.32	1.12
	DTPA Extractable	m	4.50	4.16	5.31
	H2O2 Extractable	m	110.0	108.0	103.0
6.5	Total Dissolved	0.26	0.24	0.02	0.0
	Exchangeable	0.0	0.0	0.0	0.08
	Reducible	22.4	23.9	19.9	21.9
	DTPA Extractable	5.36	5.26	4.54	3.48
	H2O2 Extractable	m	m	m	m
8.0	Total Dissolved	0.20	0.23	0.06	0.12
	Exchangeable	0.0	0.0	0.0	0.0
	Reducible	4.72	4.25	1.84	2.24
	DTPA Extractable	4.46	4.12	4.68	4.08
	H2O2 Extractable	111.0	112.0	119.0	114.0

[1] total dissolved expressed as ug/g oven dry solids basis where water to solids ratio was 5:1 (w/w).
[2] missing value.
[3] mean of duplicate subsamples.





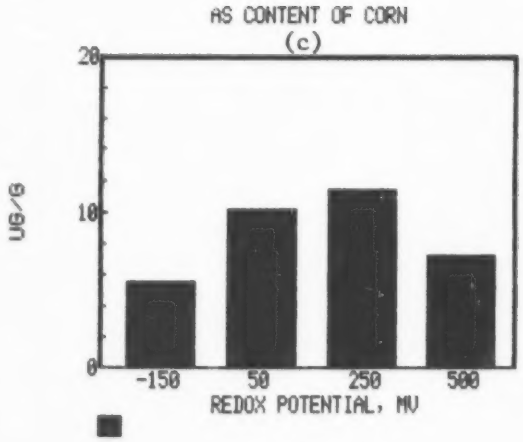


Figure 21. The effect of soil redox potential at pH 8 on levels of arsenic in readily available (a) and potentially available (b) chemical forms in a Drummer soil/Chicago reference sludge mixture and in corn plants (c) grown in this mixture.

TABLE 14. EFFECT OF PH AND REDOX POTENTIAL ON CONCENTRATIONS OF SELECTED ELEMENTS IN RICE GROWN IN SLUDGE-SOIL SUSPENSIONS

Sludge/ Soil	Element	pH	Redox Potential, mv			
			-150	50	250	500
			µg/g			
C/D†	Cu	5.0				
C/D	Cu	5.0	14.8* ± —@	29.5± —	31.5± —	29.7± —
C/D	Cu	6.5	102 ±14Δ	105 ±14	71 ± 0	84 ±13
C/L‡	Cu	6.5	58 ± 8	46 ± 2	71 ± 4	30 ± 0
C/L	Cu	8.0	20 ± 2	36 ± 4	22 ± —	24 ± 2
C/D	Zn	5.0	81 ± —	110 ± —	115 ± —	264 ± —
C/D	Zn	6.5	158 ± 9	150 ± 9	238 ±21	233 ±14
C/L	Zn	6.5	71 ± 7	65 ± 2	147 ± 6	173 ± 6
C/L	Zn	8.0	29 ± 1	26 ± 1	62 ± —	85 ± 2
C/D	Cd	5.0	—@	—	—	—
C/D	Cd	6.5	2.4 ± 1.4	2.4± 1.0	12.0± 1.4	10.8± 0.6
C/L	Cd	6.5	1.8 ± 0.5	2.9± 0.1	27.7± 0.4	52.9± 0.4
C/L	Cd	8.0	0.5 ± 0.1	1.5± 0.1	2.0± —	2.6± 0.0
C/D	Pb	5.0	—	—	—	—
C/D	Pb	6.5	6.1 ± 0.9	5.4± 0.5	6.0± 1.4	7.5± 0.6
C/L	Pb	6.5	1.7 ± 2.1	2.1± 0.9	4.4± 0.8	2.4± 1.0
C/L	Pb	8.0	1.7 ± 1.4	0.9± 1.3	4.6± —	3.5± 1.3
C/D	Cr	5.0	—	—	—	—
C/D	Cr	6.5	2.2 ± 0.9	1.8± 0.8	1.6± 0.1	1.9± 0.4
C/L	Cr	6.5	8.0 ± 1.0	7.9± 0.3	12.3± 0.4	7.7± 0.2
C/L	Cr	8.0	12.3 ± 1.0	7.4± 0.4	10.3± —	9.2± 0.3
C/D	Ni	5.0	—	—	—	—
C/D	Ni	6.5	10.4 ± 3.0	10.4± 1.0	8.8± 0.4	8.0± 0.1
C/L	Ni	6.5	7.4 ± 0.6	6.7± 0.2	8.8± 0.1	7.5± 0.4
C/L	Ni	8.0	3.9 ± 0.4	2.6± 0.3	7.0± —	5.8± 0.4
C/D	As	5.0	—	—	—	—
C/D	As	6.5	12.9 ± 0.5	13.2± 0.7	13.4± 1.5	11.8± 0.3
C/L	As	6.5	15.9± 5.8	8.0± 2.3	10.5± 5.2	7.8± 6.0
C/L	As	8.0	2.6± 3.7	4.0± 3.8	6.3± —	6.5± 4.9

†Chicago reference sludge/Drummer soil material.

‡Chicago reference sludge/Loring soil material.

*Mean.

@Missing data for one or both subsamples.

ΔStandard deviation.

TABLE 15. EFFECT OF PH AND REDOX POTENTIAL ON CONCENTRATIONS OF SELECTED ELEMENTS IN CORN GROWN IN SLUDGE-SOIL SUSPENSIONS

Sludge/ Soil	Element	pH	Redox Potential, mv -150	50	250	500
			µg/g			
C/D[@]	Cu	5.0	—[†]	19.4[‡]± 4.1[*]	13.8± 2.5	36.8± 1.8
		6.5	25.2± —	22.3 ± —	28.8± —	42.1± —
		8.0	13.2±0.3	17.1 ± 0.9	18.9± 0.6	31.8± 2.9
	Zn	5.0	—	143 ± 7	98 ±18	203 ±11
		6.5	103 ± —	184 ± —	289 ± —	925 ± —
		8.0	85 ±8	187 ±43	245 ± 6	563 ±20
	Cd	5.0	—	5.7 ± 0.9	7.7± 0.6	11.6± 0.3
		6.5	2.1± —	6.2 ± —	23.9± —	110 ± —
		8.0	0.3±0.0	0.8 ± 0.1	8.0± 0.5	11.6± 0.0
	Pb	5.0	—	4.2 ± 2.8	1.3± 0.2	4.8± 0.8
		6.5	17.4± —	21.6 ± —	14.2± —	15.3± —
		8.0	4.8±1.5	3.6 ± 0.8	5.9± 1.2	8.2± 1.8
	Cr	5.0	—	9.1 ± 0.2	7.7± 0.1	8.1± 0.0
		6.5	30.1± —	11.8 ± —	37.0± —	13.8± —
		8.0	7.6±0.2	7.8 ± 0.5	7.9± 0.4	7.4± 0.8
	Ni	5.0	—	2.5 ± 0.4	2.7± 0.8	7.0± 0.9
		6.5	16.6± —	22.8 ± —	19.7± —	19.9± —
		8.0	6.2±1.9	4.8 ± 0.1	6.2± 1.0	5.1± 0.7
	As	5.0	—	8.7 ± 4.8	12.3± 7.8	5.6± 2.4
		6.5	9.7± —	8.6 ± —	6.8± —	6.4± —
		8.0	5.7±2.6	10.2 ± 2.5	11.5± 3.9	7.4± 1.8

[†]Missing data for one or both subsamples.

[‡]Mean.

[*]Standard deviation.

[@]Chicago reference sludge/Drummer soil.

prior to transplanting the rice or corn. Therefore, it is believed that the data in Tables 7 and 8 can best be used by focusing on relative redox potential effects within a given sludge/soil mixture and pH combination. Also, for the pH 5.0 corn study, there was some concern that the plants may have been stressed, either by a toxicity effect or another factor, as metals which were expected to be present in the highest concentration in the pH 5.0 treatment (based on literature reports of pH effects on metal uptake and similar work conducted in this lab with marsh plants and dredged materials) were almost always lower than metal concentrations in the pH 6.5 treatment.

Since this report is concerned primarily with toxic and potentially toxic elements, data for Cu, Zn, Cd, Pb, Cr, Ni, and As are presented in Tables 14 and 15. Data for other elements are included in the appendices.

Of the elements summarized in Tables 14 and 15, Zn and Cd responded most strongly to redox potential conditions. For corn at pH 6.5 and 8.0, Zn levels increased from around 100 parts per million under strongly reducing conditions to greater than 900 and 500 parts per million, respectively, at the two pH levels in well oxidized sludge-soil mixtures.

Cadmium concentrations also increased dramatically as the redox potential increased from strongly reduced to well oxidized conditions in most combinations of sludge-soil mixtures and pH. For example, a 20-fold or greater increase occurred between -150 mv and 500 mv in rice grown at pH 6.5 in the Baton Rouge sludge/Loring soil suspension and in the pH 8.0 Chicago sludge/Drummer soil combination. A 50-fold increase occurred between the redox potential extremes in the Chicago sludge/Drummer soil combination incubated at pH 6.5. Gambrell et al. (1980) and Folsom et al. (1981) reported similar redox potential effects on Cd uptake by marsh plants. There were many substantial changes in concentrations of Cd (and Zn) in plant tissue between adjacent redox potential levels, which suggests that even modest changes in a soil's oxidation-reduction status can greatly affect Zn and Cd concentrations. This can be a very important consideration in managing Cd-contaminated soils.

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APPENDICES

Appendix Table A-1

TABLE A-1. EFFECT OF SLUDGE RATIO AND OXIDATION CONDITIONS ON DISSOLVED LEVELS OF SELECTED ELEMENTS FROM A SUSPENSION OF CHICAGO REFERENCE SLUDGE AND DRUMMER SOIL

RATIO %	TREAT	REP	CU	ZN	CD	PB	CR	NI	AS	FE	MN	CA	MG	MO	SI	P	AL
									UG/G D.O. SOLIDS BASIS								
1	OX	1	0.236	1.05	0.003	0.270	0.06	0.12	0.000	16.92	0.29	114	34	0.164	291	3.9	27.0
1	OX	2	0.019	0.13	0.000	0.030	0.02	0.01	0.047	2.49	0.05	15	4	0.307	28	*	2.3
1	RE	1	0.046	0.10	0.000	0.026	0.03	0.04	0.039	8.56	0.27	18	5	0.137	8	*	0.5
1	RE	2	0.053	0.06	0.001	0.036	0.02	0.05	0.083	9.59	0.40	18	5	0.135	14	*	5.8
5	OX	1	0.044	0.07	0.000	0.052	0.03	0.04	0.027	0.25	0.01	43	13	0.036	10	*	0.0
5	OX	2	0.071	0.13	0.005	0.042	0.10	0.07	0.015	0.23	0.01	71	22	0.072	24	*	1.0
5	RE	1	1.323	2.05	0.112	1.230	1.20	0.57	0.233	34.39	1.37	128	29	0.390	191	94.5	36.2
5	RE	2	1.370	1.55	0.117	0.911	1.29	0.58	0.206	29.51	1.76	134	32	0.535	224	113	37.8
25	OX	1	0.083	0.18	0.013	0.000	0.01	0.12	0.036	0.28	0.38	198	49	0.117	6	*	0.0
25	OX	2	0.473	1.54	0.130	0.000	0.13	0.99	0.000	1.06	4.48	1569	370	1.176	128	9.2	4.3
25	RE	1	0.157	0.30	0.036	0.102	0.36	0.56	0.000	6.77	1.34	534	136	0.738	91	43.9	13.4
25	RE	2	0.030	0.04	0.003	0.000	0.01	0.06	0.023	0.92	0.12	58	17	0.081	6	*	0.5
75	OX	1	0.047	0.09	0.007	0.000	0.04	0.08	0.000	0.41	0.85	450	61	0.176	6	*	1.0
75	OX	2	0.042	0.63	0.267	0.000	0.16	4.26	0.000	1.65	7.93	2926	430	1.195	38	22.8	10.6
75	RE	1	0.005	0.06	0.001	0.026	0.02	0.09	0.031	0.85	0.09	147	28	0.315	1	*	0.7
75	RE	2	0.002	0.03	0.003	0.005	0.04	0.13	0.013	1.84	0.16	252	48	0.324	11	*	1.6
100	OX	1	0.037	0.27	0.010	0.000	0.03	0.37	0.012	2.05	0.37	324	53	0.176	2	*	1.1
100	OX	2	0.000	0.46	0.000	0.000	0.13	2.94	0.000	12.24	3.16	2601	398	1.479	65	4.2	7.3
100	RE	1	0.153	0.29	0.014	0.000	0.22	0.72	0.000	16.86	0.94	1691	261	0.000	73	18.4	7.5
100	RE	2	0.223	0.19	0.048	0.000	0.17	0.62	0.213	8.31	0.78	1398	225	0.049	57	14.1	4.5

TABLE A-2. EFFECT OF SLUDGE RATIO AND OXIDATION CONDITIONS ON EXCHANGEABLE LEVELS OF SELECTED ELEMENTS FROM A SUSPENSION OF CHICAGO REFERENCE SLUDGE AND DRUMMER SOIL

RATIO %	TREAT	REP	CU	ZN	CD	PB	CR	NI	AS	FE	MN	CA	MG	MO	SI	P	AL
										UG/G							
0	OX	1	1.91	1.86	0.08	1.00	1.23	0.24	0.57	6.2	0.3	3848	771	0.20	78	6	22.3
0	OX	2	0.24	1.43	0.01	0.00	0.10	0.04	0.00	0.8	0.1	3035	588	0.00	41	2	8.9
0	RE	1	0.00	1.06	0.11	0.00	0.42	0.12	0.41	83.7	61.6	4462	858	0.00	22	5	11.2
0	RE	2	0.00	1.03	0.16	0.00	0.00	0.09	0.13	19.6	66.1	3216	612	0.00	6	1	5.0
5	OX	1	1.29	13.31	2.38	0.19	0.55	1.18	0.21	3.9	0.5	5327	943	0.06	10	30	16.7
5	OX	2	0.69	8.20	1.41	0.00	0.17	0.67	0.09	0.9	0.3	3115	553	0.03	35	16	4.9
5	RE	1	0.00	0.33	0.00	0.00	0.24	0.35	0.22	61.1	30.6	3962	727	0.02	72	56	9.6
5	RE	2	0.00	0.36	0.00	0.00	0.11	0.17	0.00	1.0	43.2	3300	594	0.00	25	24	4.4
25	OX	1	3.80	26.73	7.49	0.32	0.24	4.50	0.06	3.6	14.6	4491	736	0.41	70	42	14.3
25	OX	2	2.61	16.35	4.63	0.08	0.16	2.67	0.08	2.4	14.4	2777	464	0.25	147	26	34.2
25	RE	1	0.00	2.16	0.11	0.07	0.25	1.12	0.50	127.1	19.8	5437	812	0.36	18	171	18.1
25	RE	2	0.00	0.37	0.14	0.00	0.14	0.69	0.13	78.2	22.0	3443	496	0.16	73	116	10.9
75	OX	1	0.79	68.13	4.72	0.32	0.14	14.05	0.00	5.8	12.2	4657	462	1.12	40	18	12.4
75	OX	2	0.33	50.40	3.73	0.38	0.15	10.35	0.00	1.3	10.4	3493	353	1.10	112	13	29.9
75	RE	1	0.02	7.77	0.00	0.00	0.21	2.10	0.31	129.2	7.2	4780	530	0.27	48	115	14.9
75	RE	2	0.20	0.36	0.04	0.00	0.16	1.44	0.37	84.0	8.3	3529	402	0.19	139	78	29.3
100	OX	1	0.00	8.37	0.00	0.06	0.07	7.50	0.27	4.1	5.8	3855	350	0.77	24	13	13.0
100	OX	2	0.17	7.87	0.03	0.03	0.18	7.49	0.00	1.9	5.1	3585	324	0.97	37	11	7.2
100	RE	1	0.00	0.57	0.00	0.00	0.00	0.23	0.33	189.4	5.9	4911	476	0.17	48	127	15.7
100	RE	2	0.00	0.16	0.00	0.00	0.14	1.18	0.12	18.3	4.8	2659	265	0.02	13	22	12.2

TABLE A-3. EFFECT OF SLUDGE RATIO AND OXIDATION CONDITIONS ON DTPA EXTRACTABLE LEVELS OF SELECTED ELEMENTS FROM A SUSPENSION OF CHICAGO REFERENCE SLUDGE AND DRUMMER SOIL

RATIO %	TREAT	REP	CU	ZN	CD	PB	CR	NI	AS	FE	MN	CA	MG	MO	SI	P	AL
										UG/G							
0	OX	1	9	24	0.18	4	0.2	2.0	1.2	67	34	1406	119	0.16	136	13	20
0	OX	2	8	22	0.15	5	0.3	20.7	1.0	69	39	1424	124	0.24	71	13	23
0	RE	1	6	20	0.35	9	0.3	2.1	2.1	569	57	1199	97	0.32	165	20	48
0	RE	2	5	20	0.35	9	0.3	2.2	1.5	545	58	1248	103	0.31	117	19	35
5	OX	1	47	139	7.58	38	4.5	15.2	2.6	171	70	2150	234	0.57	201	155	103
5	OX	2	50	147	7.83	39	4.9	16.9	3.1	274	73	2265	245	0.58	238	227	111
5	RE	1	1	28	0.48	16	3.4	3.0	1.9	723	72	1711	181	0.20	158	165	74
5	RE	2	2	37	0.55	20	4.1	9.1	2.8	995	79	1999	221	0.38	216	216	90
25	OX	1	183	425	24.84	135	15.8	41.8	5.7	770	65	3349	419	1.07	278	740	261
25	OX	2	154	375	25.04	109	8.3	34.0	4.1	486	54	2850	296	0.75	212	535	170
25	RE	1	7	213	3.83	80	18.7	47.7	5.7	2187	105	3605	350	0.91	200	940	359
25	RE	2	6	206	4.21	89	19.1	46.5	6.8	2137	105	3609	358	1.10	229	957	360
75	OX	1	29	399	37.18	266	17.5	37.9	5.4	1639	86	3857	183	2.04	111	913	326
75	OX	2	31	391	38.55	274	19.4	102.0	7.1	1700	89	3967	201	1.95	269	928	387
75	RE	1	2	390	8.96	185	20.3	115.3	9.8	5391	133	5856	265	2.28	248	2192	534
75	RE	2	2	376	8.73	174	16.3	105.9	8.2	4499	114	4875	225	1.74	123	1640	454
100	OX	1	14	713	20.34	260	18.0	107.9	7.3	2596	92	4754	216	1.64	266	968	404
100	OX	2	17	764	22.56	278	20.1	114.1	7.6	2947	96	5000	227	1.89	105	1137	403
100	RE	1	3	413	9.62	184	15.7	125.3	7.6	5338	131	5822	157	1.88	234	1908	411
100	RE	2	3	389	9.21	175	10.1	125.9	6.5	6402	113	4488	80	2.04	160	1712	244

APPENDIX B

EXTRACTION SEQUENCE STUDY

Selected chemical extractions can be very valuable tools for studying the chemistry of trace and toxic metals in soils and sediments and also for estimating plant availability of metals. The relationship between various extraction methods and plant uptake of nutrient and toxic elements has been developed to the point where reliable and valuable correlation information has become routine for agricultural purposes. Most of the extraction methods employed use only a single extraction. Occasionally, a sequential procedure involving two chemical extractants is used. It would be useful for understanding the many and varied processes affecting metal mobility and plant availability if extraction procedures could be developed which would examine several of the chemical processes and forms affecting the availability of metals in sludge-amended soils. Gambrell et al. (1977a), and Gambrell, Collard, and Patrick (1980) modified published procedures in developing sequential chemical extraction procedures that were useful in evaluating the effects of sediment physicochemical properties on the chemical forms and marsh plant availability of toxic metals in sediment-water systems.

For the routine extractions planned for the controlled redox potential-pH studies of this project, we planned to use the extraction sequence: (1) water soluble, (2) exchangeable (ammonium acetate extractable), (3) reducible (oxalic acid/ammonium oxalate extractable), (4) synthetic organic chelate extractable (DTPA), and, (5) residual organic bound (H_2O_2 digestion/acid extraction). A literature survey and past experience indicated this should be a satisfactory order since the extractions are progressively harsher. However, it was decided to do a brief study at two sludge-soil ratios (0 and 25 percent) and two redox potential levels (oxidized and reduced) to examine how rearranging the sequence of the exchangeable, reducible, and DTPA extractions would affect recovery of the various metals in the different chemical forms. The extraction sequences included in this preliminary study are shown below:

It is acknowledged that chemical extractants are not totally specific for a particular chemical form to the absolute exclusion of elements in other forms; thus, some overlap may occur in the use of sequential extractions. Also, it is likely that certain rearrangements of the order of individual extractions in a sequence will affect the apparent efficiency of some extractants. For example, this preliminary study showed that placing the oxalate and/or DTPA extractant before the exchangeable extraction considerably increased exchangeable levels for many elements.

TABLE B. SEQUENCE OF EXTRACTIONS STUDIED

Sequence I.D.	Extraction Sequence (left to right)			
1	water soluble	exchangeable	reducible	DTPA extractable
2	water soluble	exchangeable	DTPA extractable	reducible
3	water soluble	reducible	exchangeable	DTPA extractable
4	water soluble	DTPA extractable	exchangeable	reducible
5	water soluble	reducible	DTPA extractable	exchangeable

This particular, unreplicated study should be considered of a preliminary nature only. However, an examination of the data for key elements for which we have considerable environmental chemistry experience confirmed that the sequence: water soluble, exchangeable, reducible, and DTPA extractable was the most appropriate for this study, though the sequence (#2) in which reducible and DTPA extractable were switched would probably be satisfactory as well. Other sequences in which a milder extractant followed a harsher extractant did not appear satisfactory.

Appendix Tables B-1 through B-4 that follow includes the data obtained in this study.

TABLE B-1. THE RECOVERY OF DISSOLVED ELEMENTS FROM CHICAGO REFERENCE SLUDGE-DRUMMER SOIL SUSPENSIONS AS AFFECTED BY EXTRACTION SEQUENCE

BASIC A	TREAT	CHICK	CU	ZN	CD	FE	CR	NI	AS	PB	MN	CA	MG	MO	SI	P	AL
			UG/G O.D. SOLIDS BASIS														
	CX	1	0.43	0.49	0.000	0.160	0.14	0.11	0.00	28.6	0.57	140	40	0.08	471	12.5	50.2
	CX	2	0.53	0.55	0.000	0.230	0.10	0.15	0.37	42.1	0.52	103	29	0.06	60	7.5	30.1
	CX	3	0.41	0.54	0.000	0.300	0.12	0.14	0.30	27.7	0.54	133	38	0.07	42	11.5	37.6
	CX	4	0.79	1.40	0.000	0.660	0.24	0.33	0.18	45.4	0.56	250	70	0.27	803	10.1	127.0
	CX	5	1.35	0.78	0.000	0.000	0.13	0.07	0.51	31.6	0.67	121	34	0.07	9	10.1	30.3
	BX	1	0.31	0.39	0.000	0.420	0.14	0.20	0.31	64.5	3.17	140	38	0.44	105	44.2	28.2
	BX	2	0.54	0.57	0.017	0.408	0.11	0.27	1.25	56.8	4.22	137	31	0.25	193	22.7	18.9
	BX	3	0.54	0.42	0.027	0.318	0.15	0.30	0.93	59.2	2.93	126	32	0.26	177	41.5	39.0
	BX	4	0.43	0.47	0.000	0.119	0.12	0.23	0.69	47.5	3.14	145	37	0.23	103	41.8	46.9
	BX	5	0.00	0.45	0.000	0.000	0.09	0.00	0.00	0.0	0.00	0	0	0.00	0	0.0	0.0
	CX	1	2.31	3.88	0.245	0.000	0.39	4.10	0.00	94.2	6.15	3414	810	2.41	312	33.5	11.5
	CX	2	1.33	1.13	0.133	0.000	0.22	1.23	0.20	24.0	3.36	1911	466	1.38	119	10.1	7.5
	CX	3	1.47	1.05	0.144	0.000	0.20	1.44	0.00	55.1	3.75	2371	599	1.72	107	25.0	8.8
	CX	4	1.42	1.09	0.174	0.000	0.43	1.33	0.33	54.0	3.34	2124	540	1.36	201	20.7	9.0
	CX	5	1.66	1.44	0.186	0.000	0.75	1.46	0.42	54.6	3.92	2232	565	1.45	182	22.7	8.5
	BX	1	0.12	1.19	0.000	0.051	0.10	0.71	0.40	11.1	0.74	657	167	1.08	89	30.4	9.2
	BX	2	0.44	0.42	0.000	0.000	0.12	0.00	0.51	8.5	0.71	541	139	0.98	56	40.5	9.0
	BX	3	0.35	0.35	0.000	0.000	0.14	0.74	0.41	15.9	0.88	507	134	0.85	74	32.0	11.5
	BX	4	0.79	0.79	0.000	0.179	0.12	0.83	0.26	11.2	0.96	680	176	1.15	85	39.9	9.7
	BX	5	0.47	0.91	0.000	0.229	0.10	0.78	0.15	8.3	0.98	563	146	0.94	40	50.8	5.9

TABLE E-2. THE RECOVERY OF EXCHANGEABLE ELEMENTS FROM CHICAGO REFERENCE SLUDGE-DRUMMER SOIL SUSPENSIONS AS AFFECTED BY EXTRACTION SEQUENCE

RATIO A	TREAT	ORDER	CU	ZN	CD	PB	CR	NI	AS	FE	MN	CA	MG	MO	SI	P	AL
										UG/G							
0	CX	1	0.26	1.7	0.08	0.25	0.19	0.16	0.17	1	0.4	3286	571	0.036	36	9.4	23
0	CX	2	0.49	1.7	0.00	0.06	0.28	0.04	0.00	1	0.4	2075	431	0.000	19	7.1	4
0	CX	3	1.36	4.9	0.13	0.41	0.38	0.57	0.35	85	1.0	17	119	0.027	265	17.9	103
0	CX	4	4.01	7.9	0.11	1.66	0.15	0.87	0.87	45	10.9	1251	232	0.114	175	0.0	39
0	RED	1	0.48	1.9	0.04	0.01	0.19	0.32	0.71	165	78.4	3788	995	0.085	57	7.4	16
0	RED	2	0.36	1.6	0.03	0.24	0.17	0.23	0.51	159	60.1	3761	695	0.033	19	0.4	19
0	RED	3	0.33	4.9	0.07	1.77	0.52	0.08	4.24	131	8.5	17	92	0.372	41	29.6	274
0	RED	4	4.77	9.0	0.17	2.70	0.40	0.35	1.23	448	15.9	833	163	0.188	129	9.0	47
45	OX	1	9.90	0.4	0.11	4.05	0.26	0.39	8.51	151	11.9	602	38	0.005	42	0.0	12
45	CX	2	4.73	19.4	3.34	0.28	0.59	3.00	0.00	5	18.0	3699	751	0.324	50	44.0	10
45	CX	3	38.80	91.0	18.09	3.11	0.55	21.10	0.71	19	16.1	3276	618	0.447	35	54.0	13
45	CX	4	6.20	56.4	0.58	2.35	34.53	8.30	3.58	256	9.8	23	434	0.007	206	312	250
45	OX	1	45.04	32.8	6.19	24.44	1.00	11.20	0.00	322	17.2	1404	319	0.206	47	407	47
45	OX	2	16.32	47.6	4.52	20.65	7.49	3.92	0.88	192	10.2	881	180	0.198	133	143	42
45	OX	3	0.74	1.0	0.05	0.00	0.26	0.00	0.27	155	27.9	4493	634	0.177	145	450	34
45	RED	1	0.13	0.0	0.02	0.07	0.00	0.00	0.00	82	8.4	1510	241	0.083	16	89.7	5
45	RED	2	0.00	25.3	0.05	1.03	22.70	7.32	2.43	284	10.3	16	293	0.295	150	319	184
45	RED	3	0.42	67.0	0.59	14.98	1.42	17.00	0.45	1070	26.7	1576	357	0.082	93	204	24
45	RED	4	1.28	91.2	1.07	23.76	7.83	9.08	1.16	497	16.2	733	243	0.134	339	226	35

TABLE B-3. THE RECOVERY OF MOBILIZABLE ELEMENTS FROM CHICAGO REFERENCE SLUDGE-DRUMMER SOIL SUSPENSIONS AS AFFECTED BY EXTRACTION SEQUENCE

BATCH	TREAT	ORDER	CU	ZN	CD	PB	CR	NI	AS	FE	MN	CA	MG	MO	SI	P	AL
											UG/G						
C	OX	1	14.30	85.0	0.18	8.91	3.44	3.0	17.6	1369	133	268	190	1.28	215	392	1283
C	OA	1	11.21	14.3	0.15	0.74	1.11	2.0	16.3	929	75	157	154	1.09	222	340	1149
C	OAX	1	12.10	30.3	0.15	0.32	0.92	2.0	14.0	969	100	370	578	0.98	94	316	1039
C	OX	2	30.30	19.0	0.10	0.21	0.91	1.4	13.0	815	76	93	129	1.00	128	313	974
C	OA	2	10.33	26.3	0.14	0.34	0.87	2.0	13.0	869	54	76	524	1.10	165	292	935
C	OAX	2	7.80	44.0	0.17	0.63	1.61	2.3	23.5	4236	66	25	200	1.85	139	467	1501
C	EEEEEE	D	1.90	43.0	0.10	0.42	2.32	2.3	10.9	1431	21	207	72	1.09	101	383	1199
C	EEEEEE	D	2.80	43.0	0.10	0.42	2.32	5.0	26.7	4480	113	85	769	2.11	221	443	1772
C	EEEEEE	D	2.90	35.0	0.17	0.63	2.32	1.6	16.2	480	5	22	119	1.04	59	388	1184
C	EEEEEE	D	1.91	35.0	0.17	0.70	2.32	4.7	25.6	4284	105	18	753	1.97	104	439	1653
A	OX	1	43.11	400.0	0.42	19.86	209.7	73.2	32.7	4027	68	220	1E3	3.35	113	4950	4112
A	OAX	1	80.34	100.0	0.42	2.43	40.5	29.7	29.7	3347	54	55	1E3	2.70	216	2300	1904
A	OX	2	191.00	400.0	0.42	2.43	67.5	30.5	30.5	3566	56	40	1E3	3.24	197	4024	1972
A	OAX	2	50.13	100.0	0.42	2.43	39.1	28.0	28.0	3317	51	28	1E3	2.62	389	4361	1920
A	OX	2	207.00	337.0	0.42	1.15	255.1	30.4	30.8	4113	56	28	1E3	3.24	496	3048	2227
A	EEEEEE	D	1.90	423.0	0.42	1.15	313.2	78.4	39.4	6715	124	231	1E3	3.00	134	3589	2909
A	EEEEEE	D	0.79	446.0	0.42	1.15	255.8	53.2	30.4	4043	25	28	743	2.59	211	1940	2354
A	EEEEEE	D	0.97	441.0	0.42	1.15	200.5	45.7	35.1	5807	61	254	678	3.05	213	3073	2690
A	EEEEEE	D	1.17	324.0	0.42	1.15	245.4	40.2	28.0	3036	22	31	996	2.54	74	1933	2187
A	EEEEEE	D	1.20	350.0	0.48	1.82	274.2	50.0	31.9	5993	51	34	1E3	3.11	256	3023	2504

TABLE B-4. THE RECOVERY OF DTPA EXTRACTABLE ELEMENTS FROM CHICAGO REFERENCE SLUDGE-FARMER SOIL SUSPENSIONS AS AFFECTED BY EXTRACTION SEQUENCE

RATIO	TREAT	ORDER	CU	ZN	CD	FE	CR	NI	AS	FE	MN	CA	MG	MO	SI	P	AL
										UG/G							
C	OX	1	3.3	7	0.09	5.9	0.0	0.9	3.94	380	27	70	25	0.43	182	81	254
	OOX	2	3.3	7	0.03	1.1	0.1	0.6	0.41	47	16	534	60	0.00	24	8	8
	OOX	3	4.4	13	0.06	8.4	0.4	1.8	1.73	118	43	808	58	0.31	100	28	57
	OOX	4	6.6	17	0.14	3.8	0.3	1.6	1.74	82	54	2847	452	0.25	437	40	58
	BBBBBB	1	2.2	10	0.06	2.6	0.2	0.5	2.37	140	12	63	93	0.44	100	33	109
	BBBBBB	2	4.4	13	0.25	8.3	1.1	1.4	4.74	883	18	56	29	0.56	177	84	234
	BBBBBB	3	4.4	15	0.21	11.3	0.4	2.2	4.01	995	23	1404	117	0.23	195	38	85
	BBBBBB	4	6.6	18	0.20	5.1	0.0	0.7	2.02	326	21	839	32	0.16	440	44	74
A		1	3.3	8	0.30	13.3	0.7	3.1	3.53	1659	148	3924	544	0.48	131	57	77
A		2	3.3	18	0.25	6.1	1.5	1.6	0.77	983	31	100	124	0.07	420	84	409
A		3	4.4	106	2.83	20.8	41.6	13.1	5.37	653	17	130	309	0.39	163	88	301
A		4	6.6	357	16.70	122.2	14.6	22.2	5.16	800	6	3256	401	0.73	222	743	438
A		1	3.3	109	7.20	35.5	18.5	9.3	2.35	389	19	1124	188	0.34	227	178	95
A		2	4.4	372	25.17	102.7	6.9	33.0	3.31	406	66	4834	570	0.67	159	444	150
A		3	6.6	144	4.90	23.5	50.4	18.2	6.44	820	27	153	496	0.98	483	530	350
A		4	8.8	171	6.16	92.4	57.7	33.5	7.79	1437	26	160	343	1.38	431	537	400
B		1	1.1	16	0.93	38.6	28.9	24.3	5.90	4148	115	4048	457	0.97	209	1245	376
B		2	4.4	103	4.36	70.3	28.5	19.1	4.37	923	8	1196	176	0.71	424	291	127
B		3	6.6	47	0.97	11.4	9.4	8.4	1.80	791	6	2257	284	0.26	57	344	124
B		4	8.8	89	1.05	16.9	36.7	14.0	3.08	950	22	124	349	0.36	241	414	280

APPENDIX TABLE C: CONCENTRATION OF SELECTED ELEMENTS IN DIFFERENT CHEMICAL FORMS, AND IN RICE TISSUE GROWN IN A SUSPENSION OF CHICAGO REFERENCE SLUDGE:DRUMMER SOIL MATERIAL.

EX	PH	SAMPLE	EH MV	REP	CU	ZN	CD	PB	CR	NI	AS	FE	MN	CA	MG	MO	SI	P	AL
												UG/G							
C	6.5	DTPA	-150	1	2.0	113.3	3.06	10.44	17.76	7.5	5.18	796.0	12.9	412	124	0.62	209	166	300.37
C	6.5	DTPA	-150	2	17.2	92.9	3.59	10.78	19.49	8.1	5.47	794.4	12.7	135	131	0.76	181	169	292.09
C	6.5	DTPA	50	1	8.3	97.9	1.95	10.42	19.32	6.7	5.22	788.5	11.3	32	118	0.62	244	169	285.41
C	6.5	DTPA	50	2	9.2	93.6	2.10	12.90	21.89	7.6	5.37	906.6	14.6	26	129	0.67	259	200	324.57
C	6.5	DTPA	250	1	15.4	71.2	1.96	10.87	21.80	6.8	4.42	609.3	16.5	94	138	0.52	146	184	252.45
C	6.5	DTPA	250	2	16.0	73.6	1.98	12.16	22.38	7.2	4.49	614.3	17.6	83	129	0.57	113	196	257.03
C	6.5	DTPA	500	1	16.7	86.7	1.99	12.30	21.64	6.5	5.38	519.9	17.7	362	124	0.58	249	210	292.98
C	6.5	DTPA	500	2	15.9	56.4	1.00	13.20	21.99	6.6	4.96	532.9	16.7	69	123	0.56	240	212	291.48
C	6.5	EXCH	-150	1	0.6	16.5	0.97	1.26	0.20	1.9	0.08	94.8	32.3	2068	360	0.15	16	31	6.43
C	6.5	EXCH	-150	2	0.8	30.3	2.27	2.90	0.33	4.6	0.45	234.9	58.4	5196	795	0.34	70	77	19.43
C	6.5	EXCH	50	1	1.1	12.8	1.67	0.30	0.16	1.1	0.00	28.2	16.6	1130	193	0.00	8	14	3.79
C	6.5	EXCH	50	2	5.0	71.0	10.56	5.83	3.59	7.0	1.44	117.3	76.3	6799	1064	0.71	88	62	32.19
C	6.5	EXCH	250	1	3.9	26.2	3.77	0.00	0.13	1.8	0.00	4.3	28.9	2738	469	0.00	19	17	7.16
C	6.5	EXCH	250	2	1.7	49.6	7.63	4.05	1.41	4.4	1.15	6.4	37.9	5346	846	0.44	53	36	29.04
C	6.5	EXCH	500	1	3.5	44.7	6.12	1.48	0.92	4.4	0.00	21.4	40.1	4010	754	0.00	23	23	15.34
C	6.5	EXCH	500	2	1.7	59.5	8.56	2.99	0.27	6.0	0.78	5.2	40.2	5811	947	0.42	83	36	24.37
C	6.5	OXAL	-150	1	4.1	326.9	4.50	14.01	134.49	43.3	6.57	4983.8	93.1	169	510	3.03	234	1676	1971.27
C	6.5	OXAL	-150	2	3.4	327.9	4.83	12.08	139.04	45.1	7.42	5194.2	95.9	42	554	3.08	89	1671	2014.61
C	6.5	OXAL	50	1	39.1	346.3	3.72	12.75	158.13	50.3	5.36	4218.1	109.1	66	532	3.05	48	1933	2102.43
C	6.5	OXAL	50	2	28.9	251.2	2.66	11.18	112.77	35.6	3.11	2874.5	75.2	60	388	2.03	66	1041	1334.42
C	6.5	OXAL	250	1	72.1	354.6	3.49	13.45	159.39	51.8	4.17	3106.5	114.0	86	570	2.82	205	1963	2052.74
C	6.5	OXAL	250	2	74.7	352.8	3.60	16.04	162.68	52.3	4.24	3124.7	115.7	36	566	2.84	38	2013	2054.70
C	6.5	OXAL	500	1	122.1	334.1	3.43	13.90	152.62	49.4	3.65	2876.3	113.6	39	552	2.66	84	1889	1964.36
C	6.5	OXAL	500	2	94.1	296.6	2.40	10.65	99.06	37.0	1.75	1503.1	93.7	331	457	1.30	33	497	941.34
C	6.5	RICE	-150	1	92.3	164.1	1.40	6.79	2.84	12.5	12.53	213.8	364.2	9515	6730	4.03	237	6445	149.05
C	6.5	RICE	-150	2	112.1	151.6	3.43	5.46	1.55	9.3	13.29	149.1	365.5	5550	5560	3.24	183	6545	99.30
C	6.5	RICE	50	1	114.4	143.2	3.07	5.38	1.29	9.7	13.73	149.3	376.2	5760	5360	3.32	131	6555	97.75
C	6.5	RICE	50	2	94.8	156.0	1.67	5.80	2.38	11.0	12.71	188.4	364.8	8785	6845	3.71	106	6705	122.45
C	6.5	RICE	250	1	71.5	223.0	10.94	5.35	1.58	8.5	14.47	108.6	662.5	7000	6060	5.23	313	5365	104.25
C	6.5	RICE	250	2	70.9	252.8	12.97	7.00	1.64	9.1	12.39	104.5	725.5	6920	5920	5.67	161	5465	122.75
C	6.5	RICE	500	1	74.1	223.4	10.34	7.95	1.64	7.9	11.95	140.1	592.5	4921	5635	4.71	131	5855	62.05
C	6.5	RICE	500	2	93.9	243.4	11.17	7.08	2.19	8.0	11.56	154.9	568.0	5525	5850	4.80	822	5830	89.15
C	6.5	TWS	-150	1	1.7	6.3	0.10	0.00	0.32	3.8	1.26	71.2	33.3	3621	798	1.01	216	5*	23.23
C	6.5	TWS	-150	2	3.1	6.4	0.21	0.94	0.52	6.2	2.32	121.9	55.1	5746	1207	1.62	293	98	21.21
C	6.5	TWS	50	1	1.3	13.1	0.24	1.08	0.91	1.6	0.07	37.4	10.2	1048	306	0.23	29	16	8.99
C	6.5	TWS	50	2	1.2	10.0	0.24	1.09	2.38	1.5	0.98	19.8	11.8	1414	349	0.43	76	14	10.56
C	6.5	TWS	250	1	1.6	2.1	0.06	0.00	0.08	0.3	0.00	2.0	3.0	468	139	0.17	9	2	0.33
C	6.5	TWS	250	2	2.2	10.4	0.28	0.86	3.76	1.3	0.71	6.6	8.2	1355	345	0.46	49	11	9.79
C	6.5	TWS	500	1	1.5	7.1	0.25	0.00	0.14	1.1	0.03	3.5	10.7	1740	495	0.45	10	7	5.69
C	6.5	TWS	500	2	1.0	6.9	0.33	0.88	0.57	1.9	0.49	7.4	12.0	2434	599	0.54	272	14	25.99

APPENDIX TABLE D1. LEVELS OF SELECTED ELEMENTS IN CORN TISSUE AND TOTAL WATER SOLUBLE, EXCHANGEABLE, AND DTPA EXTRACTS USING DRUMMER SOIL MATERIAL INCUBATED WITH AEROBICALLY AND ANAEROBICALLY DIGESTED BATON ROUGE SLUDGE.

SAMPLE	TREAT	RATIO 1	REP	CU	ZN	CD	FE	CR	NI	AS	PE	MN	CA	MG	NO	SI	P	AL
											UG/G							
CCBN		0	1	19.42	195.75	0.909	8.03	8.607	2.824	4.75	180.3	127.50	10566	8510	3.316	99	8539.5	117
CCBN		0	2	23.44	174.74	1.414	6.75	8.948	3.009	2.95	163.0	119.66	10543	9259	2.491	48	8801.7	77
CCBN	AEBO	1	1	22.13	159.57	1.026	6.03	7.769	5.950	5.39	198.6	120.45	8313	9029	4.063	58	7341.6	94
CCBN	AEBO	1	2	16.45	162.12	1.562	2.89	12.044	2.075	2.01	138.1	143.81	10319	7150	3.594	76	7931.2	55
CCBN	AEBO	2	1	15.27	180.58	0.764	5.04	11.798	2.314	1.79	183.1	151.66	9665	7430	3.760	69	7918.4	58
CCBN	AEBO	2	2	11.17	124.26	0.643	3.49	8.926	2.780	2.04	102.7	111.45	8247	6700	3.424	41	5926.8	38
CCBN	AEBO	3	1	13.66	162.25	1.296	4.94	14.384	2.248	1.75	121.3	107.56	7675	6123	3.831	36	6916.0	65
CCBN	AEBO	3	2	11.26	118.24	0.698	1.41	5.596	1.570	0.44	107.8	121.73	7355	6996	3.881	46	5189.7	47
CCBN	AEBO	5	1	14.99	147.05	0.788	7.23	13.083	2.492	3.95	119.2	133.79	7720	7500	7.220	51	5865.9	73
CCBN	AEBO	5	2	7.98	96.30	0.325	6.79	7.805	4.919	2.51	206.8	151.90	12291	5119	2.087	44	5458.0	70
CCBN	ANAE	1	1	28.00	210.76	2.623	0.15	9.088	3.238	0.28	153.1	159.02	10574	8414	1.783	105	7835.0	35
CCBN	ANAE	1	2	16.72	148.33	1.008	3.17	5.834	1.850	2.11	116.6	128.51	8554	7796	3.129	152	7044.5	50
CCBN	ANAE	2	1	15.18	145.03	1.089	2.27	12.057	1.467	1.39	132.9	157.12	10176	7191	3.375	40	6977.3	49
CCBN	ANAE	2	2	21.31	202.15	1.549	5.78	14.440	2.659	6.04	196.4	177.24	10037	11157	4.235	50	6156.7	75
CCBN	ANAE	3	1	12.23	141.90	1.001	3.16	5.453	1.728	1.79	101.3	125.26	8310	7143	3.221	29	5295.3	47
CCBN	ANAE	3	2	17.19	209.67	1.147	2.17	6.012	1.747	1.33	132.9	175.86	9633	8553	4.483	36	6615.4	44
CCBN	ANAE	5	1	15.80	181.71	0.825	6.11	5.973	2.051	2.83	172.8	121.99	7500	5983	2.526	40	6912.3	65
CCBN	ANAE	5	2	20.39	228.94	1.302	6.41	20.450	3.923	3.49	206.8	166.72	13876	9185	3.826	82	9419.6	71
D1PA	AEBO	1	1	2.53	26.61	0.181	4.20	0.041	1.451	0.46	40.9	35.81	506	97	0.038	60	7.7	23
D1PA	AEBO	1	2	2.62	29.84	0.204	5.03	0.036	1.623	0.40	42.8	38.64	514	95	0.043	5	8.9	22
D1PA	AEBO	2	1	3.26	30.24	0.203	5.86	0.037	1.491	0.43	91.8	56.43	502	100	0.058	27	7.7	18
D1PA	AEBO	2	2	2.99	28.92	0.221	5.49	0.034	1.576	0.53	47.8	38.11	487	95	0.049	61	10.7	28
D1PA	AEBO	3	1	3.52	33.79	0.244	6.52	0.034	1.531	0.44	58.5	40.90	465	97	0.050	52	9.2	26
D1PA	AEBO	3	2	4.10	34.22	0.269	6.28	0.040	1.595	0.31	52.9	36.93	500	99	0.053	29	9.7	19
D1PA	AEBO	5	1	4.58	44.61	0.317	7.91	0.044	1.637	0.32	59.7	36.09	583	101	0.058	29	9.9	21
D1PA	AEBO	5	2	0.70	6.25	0.032	0.18	0.075	1.393	0.46	.	10.17	649	164	0.086	137	10.2	11
D1PA	ANAE	1	1	2.71	25.55	0.187	4.32	0.041	1.681	0.39	42.0	37.88	545	114	0.050	69	11.0	33
D1PA	ANAE	1	2	2.90	26.38	0.203	4.52	0.031	1.626	0.32	45.5	41.26	497	102	0.025	59	7.2	28
D1PA	ANAE	2	1	2.96	26.43	0.203	4.33	0.033	1.632	0.29	43.0	37.68	477	99	0.016	29	7.9	21
D1PA	ANAE	2	2	3.25	28.98	0.217	5.63	0.034	1.504	0.34	46.0	36.55	485	100	0.037	25	8.4	23
D1PA	ANAE	3	1	3.47	30.78	0.239	5.88	0.041	1.685	0.41	49.3	38.97	508	102	0.039	59	10.2	31
D1PA	ANAE	3	2	3.68	32.25	0.259	6.48	0.037	1.732	0.33	52.6	40.48	515	104	0.039	24	9.7	24
D1PA	ANAE	5	1	0.00	41.74	0.291	6.87	0.038	1.842	0.40	81.9	45.24	533	120	0.056	58	1.9	28
D1PA	ANAE	5	2	3.77	30.27	0.185	6.22	0.046	1.758	0.35	144.4	61.71	333	113	0.071	42	5.0	22
EXCH		0	1	0.34	1.26	0.039	0.15	0.098	0.075	0.08	0.6	0.94	2474	592	0.003	4	1.8	5
EXCH		0	2	0.54	1.46	0.061	0.09	0.101	0.089	0.10	0.7	1.62	2896	683	0.008	3	2.2	6
EXCH	AEBO	1	1	0.46	1.22	0.033	0.00	0.094	0.025	0.00	1.0	1.38	2329	445	0.000	1	1.7	5
EXCH	AEBO	1	2	0.13	1.43	0.028	0.00	0.080	0.039	0.00	0.9	1.68	2514	469	0.000	2	1.8	5
EXCH	AEBO	2	1	0.13	1.21	0.028	0.06	0.078	0.056	0.00	0.9	2.85	2356	455	0.000	2	1.8	4
EXCH	AEBO	2	2	0.19	1.60	0.031	0.00	0.091	0.020	0.00	0.8	2.23	2449	454	0.000	7	1.8	5
EXCH	AEBO	3	1	0.44	1.87	0.049	0.03	0.101	0.091	0.06	1.2	2.68	2689	619	0.009	3	2.5	6
EXCH	AEBO	3	2	0.25	1.63	0.033	0.00	0.092	0.054	0.08	3.3	2.43	2397	556	0.000	7	2.2	9
EXCH	AEBO	5	1	0.23	1.94	0.050	0.25	0.103	0.091	0.15	1.5	2.09	2252	514	0.028	3	2.3	6
EXCH	AEBO	5	2	0.22	1.41	0.014	0.13	0.105	0.130	0.13	2.8	4.41	2637	614	0.019	3	1.9	6
EXCH	ANAE	1	1	0.24	1.46	0.044	0.39	0.119	0.138	0.18	0.9	2.09	2421	589	0.045	3	2.2	7
EXCH	ANAE	1	2	0.35	1.23	0.030	0.03	0.091	0.049	0.08	0.9	2.18	2298	546	0.003	7	1.7	5
EXCH	ANAE	2	1	0.01	1.28	0.021	0.06	0.089	0.048	0.00	0.6	1.69	2258	422	0.000	3	1.7	5
EXCH	ANAE	2	2	0.01	1.41	0.035	0.00	0.087	0.026	0.00	1.1	2.50	2415	450	0.000	3	2.1	5
EXCH	ANAE	3	1	0.04	1.68	0.025	0.00	0.094	0.020	0.00	1.7	3.22	2504	457	0.000	4	2.0	6
EXCH	ANAE	3	2	0.22	1.51	0.033	0.00	0.094	0.057	0.00	1.2	2.78	2402	440	0.000	4	2.2	6
EXCH	ANAE	5	1	0.42	2.99	0.051	0.13	0.086	0.093	0.07	2.4	6.11	2621	596	0.000	5	2.8	7
EXCH	ANAE	5	2	0.61	1.79	0.025	0.06	0.101	0.021	0.05	1.8	11.09	2733	641	0.000	3	2.3	7
TWS		0	1	0.39	0.98	0.022	0.50	0.165	0.174	1.28	85.7	0.39	3	2	0.116	54	5.9	92
TWS		0	2	0.78	0.56	0.005	0.10	0.088	0.118	0.28	16.9	0.10	36	13	0.023	14	3.2	16
TWS	AEBO	1	1	0.34	1.33	0.010	0.66	0.182	0.177	1.55	89.7	0.45	32	23	0.138	79	6.5	99
TWS	AEBO	1	2	0.41	0.76	0.010	0.62	0.125	0.160	1.10	75.8	0.39	26	19	0.102	22	4.9	88
TWS	AEBO	2	1	0.29	0.49	0.019	0.66	0.056	0.168	0.37	11.1	0.18	33	11	0.114	10	3.0	15
TWS	AEBO	2	2	0.29	0.06	0.022	0.56	0.031	0.118	0.02	10.0	0.12	6	2	0.026	6	1.0	17
TWS	AEBO	3	1	0.48	0.00	0.018	0.58	0.019	0.099	0.00	0.4	0.07	3	0	0.009	1	0.5	7
TWS	AEBO	3	2	0.30	1.89	0.023	0.75	0.171	0.259	1.13	74.8	0.43	30	19	0.139	33	6.1	85
TWS	AEBO	5	1	0.28	1.14	0.000	0.61	0.150	0.175	1.16	77.3	0.40	39	21	0.119	78	7.1	85
TWS	AEBO	5	2	0.15	1.22	0.000	0.18	0.045	0.217	0.15	1.4	4.54	250	77	0.065	7	2.1	3
TWS	ANAE	1	1	0.05	0.13	0.000	0.14	0.026	0.004	0.16	5.9	0.06	13	5	0.014	6	1.2	8
TWS	ANAE	1	2	0.11	0.50	0.000	0.19	0.116	0.085	0.80	61.9	0.34	31	17	0.056	73	5.0	66
TWS	ANAE	2	1	0.11	1.40	0.000	0.54	0.202	0.167	1.64	122.1	0.58	46	29	0.103	145	8.8	131
TWS	ANAE	2	2	0.71	0.47	0.000	0.03	0.063	0.081	0.38	32.3	0.17	31	13	0.010	14	4.0	36
TWS	ANAE	3	1	0.28	0.49	0.000	0.54	0.120	0.148	1.07	75.2	0.38	37	19	0.096	7	6.4	84
TWS	ANAE	3	2	0.20	0.39	0.000	0.43	0.102	0.139	0.88	59.3	0.29	32	16	0.075	41	5.4	66
TWS	ANAE	5	1	0.47	0.18	0.000	0.00	0.022	0.067	0.00	2.2	0.08	52	15	0.000	3	2.3	2
TWS	ANAE	5	2	0.31	0.15	0.000	0.00	0.024	0.091	0.05	3.3	0.16	61	19	0.000	5	2.3	3

APPENDIX TABLE B2. LEVELS OF SELECTED ELEMENTS IN RICE TISSUE AND TOTAL WATER SOLUBLE, EXCHANGEABLE, AND DTPA EXTRACTS USING DRUMMER SOIL MATERIAL INCUBATED WITH AEROBICALLY AND ANAEROBICALLY DIGESTED BATON ROUGE SLUDGE.

SAMPLE	TREAT	RATIO 1	REP	CU	ZN	CD	FE	CR	NI	AS	FE	MN	CA	MG	MO	SI	P	AL
											UG/G							
DTPA		C	1	2.01	43.38	0.147	3.41	0.051	1.458	0.18	46.2	30.55	936	281	0.000	55	2.5	14
DTPA	AEBO	1	1	1.07	19.25	0.076	1.11	0.064	1.526	0.19	211.1	36.56	1026	323	0.020	107	3.5	16
DTPA	AEBO	1	2	0.92	6.78	0.044	0.09	0.074	1.011	1.56	292.5	11.56	604	273	0.036	94	1.8	14
DTPA	AEBO	2	1	0.67	3.40	0.009	0.00	0.055	0.808	0.08	276.1	11.47	710	295	0.000	50	1.8	3
DTPA	AEBO	2	2	0.28	3.38	0.012	0.00	0.054	0.831	.	255.3	11.40	573	287	0.005	28	1.3	1
DTPA	AEBO	3	1	0.17	17.78	0.006	0.00	0.068	0.860	0.05	300.3	10.13	794	296	0.001	27	2.2	5
DTPA	AEBO	3	2	0.31	3.96	0.012	0.00	0.046	0.799	0.02	272.0	12.81	559	277	0.000	62	1.7	4
DTPA	AEBO	5	1	0.69	5.48	0.022	0.00	0.069	1.072	0.19	292.9	15.63	534	306	0.032	139	2.4	18
DTPA	AEBO	5	2	0.63	4.03	0.019	0.00	0.069	0.964	0.10	268.4	11.22	748	291	0.035	86	2.4	5
DTPA	ANAE	1	1	0.47	4.72	0.016	0.00	0.062	0.922	0.09	416.6	17.62	950	344	0.000	71	2.1	4
DTPA	ANAE	1	2	0.41	5.86	0.040	0.00	0.076	1.108	0.19	341.1	14.60	707	304	0.008	100	2.1	15
DTPA	ANAE	2	1	0.09	1.47	0.000	0.00	0.054	0.777	0.12	229.9	11.70	648	332	0.000	84	1.7	12
DTPA	ANAE	2	2	0.27	2.45	0.014	0.00	0.046	0.948	0.04	322.7	14.41	756	308	0.000	46	2.0	0
DTPA	ANAE	3	1	0.22	4.16	0.000	0.00	0.085	1.510	0.31	488.1	20.26	1168	458	0.009	184	3.0	19
DTPA	ANAE	3	2	0.17	2.37	0.000	0.00	0.066	1.050	0.13	253.6	13.38	488	306	0.011	95	1.6	12
DTPA	ANAE	5	1	0.10	1.77	0.011	0.00	0.053	1.143	0.05	273.1	13.28	841	304	0.027	56	2.8	5
DTPA	ANAE	5	2	0.36	4.78	0.000	0.00	0.074	1.246	0.19	323.4	17.46	1084	315	0.034	123	3.8	15
EXCH		C	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
EXCH		C	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
EXCH	AEBO	1	1	0.16	0.81	0.026	0.17	0.052	0.075	0.11	2.2	20.38	2149	426	0.016	2	1.2	5
EXCH	AEBO	1	2	0.35	0.79	0.018	0.00	0.080	0.040	0.00	3.0	26.49	1970	380	0.000	2	1.0	4
EXCH	AEBO	2	1	0.13	0.90	0.018	0.34	0.106	0.118	0.14	6.1	39.64	2339	549	0.040	2	1.4	6
EXCH	AEBO	2	2	0.18	0.77	0.024	0.35	0.108	0.123	0.19	4.2	35.93	2366	554	0.047	3	1.5	7
EXCH	AEBO	3	1	0.17	0.67	0.009	0.00	0.085	0.085	0.00	7.3	35.82	2399	435	0.000	2	1.3	5
EXCH	AEBO	3	2	0.12	0.60	0.000	0.00	0.072	0.082	0.00	6.1	34.00	2096	396	0.000	2	1.1	4
EXCH	AEBO	5	1	0.34	0.82	0.012	0.10	0.084	0.100	0.08	6.3	36.49	2349	538	0.000	2	1.3	5
EXCH	AEBO	5	2	0.20	0.55	0.015	0.07	0.059	0.113	0.06	7.7	33.81	2112	489	0.000	3	1.4	5
EXCH	ANAE	1	1	0.56	0.91	0.036	0.16	0.082	0.120	0.13	2.1	29.37	2329	557	0.017	2	1.2	5
EXCH	ANAE	1	2	0.15	1.20	0.020	0.18	0.085	0.077	0.09	5.3	34.96	2241	532	0.012	2	1.2	5
EXCH	ANAE	2	1	0.12	0.39	0.015	0.33	0.102	0.124	0.17	9.8	37.57	2266	540	0.026	2	1.5	6
EXCH	ANAE	2	2	0.39	0.53	0.010	0.00	0.079	0.071	0.00	7.2	30.64	2342	426	0.000	2	1.3	5
EXCH	ANAE	3	1	0.03	0.37	0.009	0.00	0.081	0.085	0.00	9.4	32.34	2021	375	0.000	2	1.2	5
EXCH	ANAE	3	2	0.17	0.27	0.006	0.00	0.060	0.074	0.00	22.7	34.65	2178	403	0.000	2	1.2	4
EXCH	ANAE	5	1	0.19	0.22	0.009	0.00	0.681	0.095	0.02	29.0	35.21	1999	374	0.000	3	1.6	5
EXCH	ANAE	5	2	0.09	0.15	0.010	0.00	0.080	0.079	0.00	30.7	35.83	2050	372	0.009	1	1.6	4
RICE		0	1	41.12	297.52	4.008	15.96	4.550	4.856	18.26	784.6	767.57	5936	6037	6.292	144	6220.0	937
RICE		0	2	43.58	393.04	5.833	20.04	6.257	6.825	21.61	863.1	865.83	7430	6604	7.700	146	7788.0	1003
RICE	AEBO	1	1	31.82	147.73	2.421	15.37	7.580	5.255	23.86	2872.4	1266.88	5302	4170	7.325	154	6475.4	1348
RICE	AEBO	1	2	30.21	142.63	1.774	20.36	7.729	5.414	29.71	4109.0	1289.47	5823	4706	12.985	197	7548.9	1042
RICE	AEBO	2	1	16.22	88.88	0.874	14.27	6.720	4.322	35.06	6016.1	611.35	5142	4093	19.357	171	6109.1	678
RICE	AEBO	2	2	16.78	88.44	0.702	16.69	7.225	4.561	32.19	5710.5	575.11	5111	4239	21.212	216	5488.0	691
RICE	AEBO	3	1	14.41	81.69	1.138	19.43	7.920	4.747	38.47	5290.8	433.79	5370	4777	28.920	239	5664.4	804
RICE	AEBO	3	2	13.85	90.40	0.865	15.84	5.293	4.448	29.16	4784.1	535.49	4873	4053	21.805	153	5796.3	743
RICE	AEBO	5	1	15.95	97.27	1.034	18.22	6.458	5.040	38.11	5641.2	473.56	5194	4804	20.855	149	6371.8	1081
RICE	AEBO	5	2	10.75	94.74	1.172	11.12	3.883	4.398	31.06	6106.2	489.21	6177	5457	19.737	150	7135.8	726
RICE	ANAE	1	1	18.55	106.90	1.019	12.78	3.998	3.005	25.42	3787.9	1033.67	4737	4089	10.791	155	5915.8	1205
RICE	ANAE	1	2	21.84	130.40	1.540	16.86	4.456	3.359	17.95	2401.2	1201.84	4988	4345	8.095	145	6031.9	783
RICE	ANAE	2	1	28.55	90.65	2.654	11.27	5.250	4.058	25.19	4552.9	600.58	5386	4669	15.490	136	6015.4	595
RICE	ANAE	2	2	16.48	93.33	1.160	12.38	3.313	6.040	29.98	5780.0	551.60	5216	4990	15.640	172	5981.3	613
RICE	ANAE	3	1	11.21	73.79	1.037	12.42	3.546	4.374	27.81	4480.8	471.31	4914	4751	13.974	131	5446.3	690
RICE	ANAE	3	2	15.41	99.72	1.145	10.45	4.999	5.007	32.62	5609.2	645.72	6053	5607	15.599	152	6577.0	806
RICE	ANAE	5	1	12.24	57.91	0.979	14.38	3.837	4.867	31.38	5178.9	403.68	5159	4992	12.776	118	5715.0	1144
RICE	ANAE	5	2	13.28	61.25	0.928	12.68	4.196	5.227	25.51	5345.8	385.98	7210	6739	10.959	116	6872.2	863
TWS		0	1	0.53	5.22	0.000	0.27	0.049	0.380	0.20	3.1	5.10	58	17	0.026	1	1.0	4
TWS		0	2	0.41	0.20	0.003	0.35	0.036	0.168	0.23	1.5	0.05	101	33	0.039	2	1.4	3
TWS	AEBO	1	1	0.39	0.16	0.012	0.22	0.047	0.165	0.16	1.4	0.69	92	31	0.052	2	1.0	2
TWS	AEBO	1	2	0.63	0.22	0.009	0.02	0.048	0.146	0.10	1.7	1.04	100	34	0.033	1	1.4	2
TWS	AEBO	2	1	0.77	0.10	0.000	0.00	0.041	0.091	0.00	0.6	1.59	124	41	0.000	1	0.4	1
TWS	AEBO	2	2	0.37	0.32	0.004	0.26	0.046	0.231	0.00	2.9	1.78	151	56	0.066	5	2.1	3
TWS	AEBO	3	1	0.00	0.33	0.000	0.01	0.014	0.137	0.15	1.7	1.52	130	42	0.015	3	1.6	2
TWS	AEBO	3	2	0.06	0.21	0.000	0.07	0.015	0.084	0.18	1.6	1.09	92	29	0.005	2	1.4	2
TWS	AEBO	5	1	0.11	0.56	0.000	0.00	0.021	0.105	0.18	2.5	1.14	105	32	0.002	3	2.0	2
TWS	AEBO	5	2	0.01	0.20	0.000	0.28	0.009	0.172	0.24	2.2	1.18	107	32	0.071	4	2.3	3
TWS	ANAE	1	1	0.15	0.07	0.000	0.12	0.003	0.105	0.18	1.2	0.58	96	31	0.000	1	0.8	2
TWS	ANAE	1	2	0.26	0.48	0.000	0.10	0.042	0.121	0.15	4.8	0.82	85	28	0.010	2	1.0	0
TWS	ANAE	2	1	0.33	0.20	0.000	0.25	0.030	0.253	0.21	2.4	1.87	149	47	0.057	4	1.4	3
TWS	ANAE	2	2	0.13	0.55	0.000	0.12	0.050	0.184	0.14	2.3	1.51	125	38	0.057	3	1.5	2
TWS	ANAE	3	1	0.47	0.13	0.000	0.00	0.042	0.152	0.04	2.8	1.57	127	39	0.014	2	1.5	2
TWS	ANAE	3	2	0.67	0.15	0.000	0.00	0.003	0.120	0.00	1.9	1.30	101	32	0.000	2	1.0	1
TWS	ANAE	5	1	0.73	0.12	0.000	0.02	0.034	0.187	0.16	2.0	1.84	152	47	0.003	4	2.0	1
TWS	ANAE	5	2	0.66	2.01	0.001	0.15	0.045	0.332	0.22	10.3	4.82	378	114	0.073	7	3.7	5

APPENDIX TABLE DJ. LEVELS OF SELECTED ELEMENTS IN SOYBEANS AND TOTAL BATIK SOLUBLE, EXCHANGEABLE, AND DTPA EXTRACTS USING DRUMMER SOIL MATERIAL INCUBATED WITH AEROBICALLY AND ANAEROBICALLY DIGESTED BATON ROUGE SLUDGE.

SAMPLE	TREAT	RATIO %	REP	CU	ZN	CD	PB	CR	NI	AS	FE	BA	CA	MG	MO	SI	P	AL
										UG/G								
DTPA		0	1	2.29	23.12	0.175	3.85	0.045	1.572	0.35	36.1	33.64	551	131	0.071	39	11.8	24
DTPA		0	2	2.64	23.18	0.177	3.70	0.039	1.626	0.30	36.9	37.37	524	117	0.039	55	9.9	22
DTPA	AEBC	1	1	2.66	25.59	0.194	4.06	0.030	1.548	0.25	0.4	36.06	525	116	0.037	38	9.8	19
DTPA	AEBC	1	2	2.93	26.61	0.203	4.54	0.031	1.544	0.22	40.3	37.75	506	110	0.029	21	9.6	17
DTPA	AEBO	2	1	3.33	29.35	0.241	5.22	0.048	1.628	0.27	43.6	36.66	492	109	0.056	24	9.7	18
DTPA	AEBO	2	2	2.96	27.62	0.222	4.75	0.043	1.493	0.25	40.9	34.89	432	117	0.047	27	7.6	18
DTPA	AEBO	3	1	3.62	33.01	0.272	7.00	0.045	1.605	0.92	51.4	39.63	532	115	0.051	22	9.6	19
DTPA	AEBO	3	2	3.46	32.76	0.262	5.76	0.049	1.578	0.27	46.2	38.90	515	115	0.052	28	10.3	17
DTPA	AEBO	5	1	4.80	39.12	0.316	8.15	0.049	1.673	0.25	57.8	37.56	482	111	0.060	36	37.1	14
DTPA	AEBO	5	2	0.47	10.38	0.069	0.37	0.061	1.603	0.28	491.6	6.61	2765	124	0.132	39	3.8	2
DTPA	ANAE	1	1	2.76	24.40	0.204	4.43	0.048	1.560	0.36	39.8	35.86	507	109	0.052	53	13.3	25
DTPA	ANAE	1	2	3.20	28.48	0.232	6.52	0.045	1.721	0.33	47.0	41.42	459	110	0.054	45	10.6	21
DTPA	ANAE	2	1	3.30	29.04	0.244	5.52	0.045	1.599	0.29	42.8	24.54	461	115	0.053	26	6.8	16
DTPA	ANAE	2	2	3.25	29.79	0.240	5.39	0.047	1.569	0.35	43.2	37.37	503	114	0.054	21	7.9	20
DTPA	ANAE	3	1	4.09	33.92	0.271	7.18	0.049	1.798	0.35	64.4	45.29	492	110	0.070	24	10.6	22
DTPA	ANAE	3	2	4.64	35.74	0.282	7.56	0.044	1.844	0.49	58.8	43.44	497	119	0.077	34	9.8	26
DTPA	ANAE	5	1	5.23	38.06	0.254	10.80	0.063	1.934	0.34	140.4	71.68	407	118	0.096	23	8.1	16
DTPA	ANAE	5	2	4.90	37.19	0.290	8.98	0.060	1.870	0.44	79.7	46.88	499	122	0.091	50	7.1	28
EXCH		0	1	0.13	1.24	0.035	0.19	0.091	0.075	0.15	0.7	1.99	2319	581	0.025	2	3.1	5
EXCH		0	2	0.00	1.17	0.025	0.00	0.094	0.021	0.00	0.8	1.80	2336	461	0.000	4	2.5	4
EXCH	AEBO	1	1	0.23	1.02	0.042	0.21	0.065	0.077	0.12	0.4	1.07	1787	438	0.023	1	2.0	4
EXCH	AEBO	1	2	0.22	1.26	0.030	0.00	0.083	0.040	0.04	0.5	1.97	2096	505	0.000	2	2.0	4
EXCH	AEBO	2	1	0.18	1.55	0.042	0.15	0.101	0.089	0.12	0.6	1.53	2392	579	0.029	2	2.6	6
EXCH	AEBO	2	2	0.25	1.46	0.041	0.08	0.101	0.065	0.11	0.6	1.72	2344	573	0.000	2	2.3	5
EXCH	AEBO	3	1	0.32	4.78	0.063	0.00	0.108	0.080	0.00	0.8	2.07	2483	465	0.003	4	3.0	5
EXCH	AEBO	3	2	0.00	1.54	0.035	0.00	0.112	0.044	0.00	1.0	2.00	2459	468	0.000	3	2.6	5
EXCH	AEBO	5	1	0.02	1.65	0.043	0.00	0.089	0.042	0.00	0.7	2.77	2481	457	0.000	2	2.9	5
EXCH	AEBO	5	2	0.02	1.14	0.000	0.00	0.078	0.033	0.00	1.1	24.32	1967	372	0.000	1	1.5	4
EXCH	ANAE	1	1	0.22	1.54	0.053	0.00	0.103	0.089	0.00	0.5	1.63	2577	499	0.000	0	3.2	6
EXCH	ANAE	1	2	0.65	2.86	0.068	0.09	0.128	0.096	0.15	2.3	3.70	3407	811	0.014	5	3.4	7
EXCH	ANAE	2	1	0.46	2.02	0.050	0.08	0.086	0.067	0.10	1.0	2.37	2240	543	0.010	2	2.3	5
EXCH	ANAE	2	2	0.23	1.37	0.032	0.00	0.069	0.053	0.06	0.6	1.80	2111	506	0.000	2	2.3	4
EXCH	ANAE	3	1	0.28	1.80	0.041	0.14	0.095	0.081	0.11	0.6	4.17	2460	568	0.018	3	2.8	5
EXCH	ANAE	3	2	0.38	1.87	0.082	0.41	0.101	0.157	0.23	0.8	4.51	2467	578	0.063	2	3.1	7
EXCH	ANAE	5	1	0.28	2.22	0.051	0.39	0.115	0.138	0.16	2.7	12.03	2653	605	0.058	4	2.9	8
EXCH	ANAE	5	2	0.25	1.65	0.028	0.00	0.077	0.047	0.00	1.0	8.07	2188	407	0.000	3	2.0	4
SCTB		0	1	86.89	97.67	0.662	13.58	8.110	9.909	11.74	229.9	57.76	18315	5735	6.119	54	7038.8	143
SCTB		0	2	86.99	105.58	0.767	10.62	2.440	6.614	7.84	146.3	48.50	12739	5176	3.536	29	4992.0	108
SCTB	AEBO	1	1	31.06	100.75	2.049	5.02	3.994	10.197	2.70	197.7	56.87	14464	5876	5.188	25	7091.2	142
SCTB	AEBO	1	2	15.98	72.32	0.808	3.35	1.549	4.419	1.84	149.2	58.73	13779	5195	4.360	23	4226.4	89
SCTB	AEBO	2	1	15.54	84.43	0.993	3.39	2.710	5.389	2.73	140.5	51.32	12543	5017	4.669	24	4509.8	74
SCTB	AEBO	2	2	14.68	74.44	0.878	10.42	3.714	5.204	6.33	141.3	55.43	11387	4418	4.816	45	4724.5	111
SCTB	AEBO	3	1	17.17	76.51	1.289	5.17	1.805	6.832	4.00	149.1	47.83	12792	5044	4.041	22	5081.9	111
SCTB	AEBO	3	2	17.17	88.57	1.136	8.33	3.687	8.360	6.96	159.7	52.47	13716	5715	4.878	30	4906.6	110
SCTB	AEBO	5	1	15.21	85.41	0.923	8.78	2.488	6.672	6.70	192.3	54.61	11582	4726	9.341	26	4712.0	172
SCTB	AEBO	5	2	86.43	83.77	1.350	36.93	1.117	12.393	22.21	399.4	78.65	11298	5264	15.828	86	7957.1	333
SCTB	ANAE	1	1	13.15	86.02	0.856	1.91	2.055	5.982	4.73	159.9	63.47	12900	5311	2.948	29	4603.7	113
SCTB	ANAE	1	2	13.52	81.12	0.836	1.41	2.507	6.182	4.21	120.2	54.38	12082	4676	3.545	22	4572.0	74
SCTB	ANAE	2	1	13.98	63.38	0.792	10.93	2.452	5.589	7.47	160.6	60.17	12056	5056	3.672	35	3208.7	118
SCTB	ANAE	2	2	17.09	85.32	0.945	7.80	2.981	8.300	6.47	191.9	64.73	13250	5380	4.794	49	5142.2	132
SCTB	ANAE	3	1	15.60	81.32	0.947	8.93	1.916	6.971	5.58	118.2	55.56	10473	4226	3.923	32	4795.6	88
SCTB	ANAE	3	2	16.63	78.24	0.836	5.93	2.277	6.125	7.24	120.6	54.81	11980	4825	5.809	34	4121.7	97
SCTB	ANAE	5	1	17.10	64.11	0.951	12.32	2.368	7.702	9.10	131.9	38.01	12960	4605	8.543	28	4855.5	107
SCTB	ANAE	5	2	19.27	108.96	1.141	5.41	2.462	10.304	7.61	143.1	60.68	14230	5296	4.962	25	4861.2	106
TWS		0	1	0.17	0.21	0.005	0.00	0.043	0.117	0.24	0.6	0.15	180	73	0.075	8	4.2	3
TWS		0	2	0.32	0.18	0.001	0.00	0.022	0.116	0.16	0.5	0.09	128	52	0.020	7	3.4	1
TWS	AEBO	1	1	0.16	0.12	0.000	0.00	0.012	0.022	0.00	0.6	0.03	78	25	0.000	5	2.8	0
TWS	AEBO	1	2	0.36	0.05	0.000	0.00	0.010	0.016	0.00	0.4	0.03	48	15	0.000	4	1.9	0
TWS	AEBO	2	1	0.33	0.31	0.000	0.00	0.012	0.071	0.00	0.9	0.03	71	22	0.000	2	2.7	0
TWS	AEBO	2	2	0.27	0.47	0.000	0.00	0.039	0.144	0.00	1.4	0.04	73	27	0.003	4	1.6	0
TWS	AEBO	3	1	0.31	1.04	0.000	0.00	0.037	0.145	0.00	1.0	0.05	79	29	0.026	6	3.0	2
TWS	AEBO	3	2	0.24	0.27	0.010	0.13	0.036	0.109	0.00	1.0	0.05	97	24	0.033	5	3.0	1
TWS	AEBO	5	1	0.50	0.20	0.000	0.00	0.015	0.078	0.01	0.8	0.04	78	23	0.015	4	2.7	1
TWS	AEBO	5	2	1.67	0.20	0.000	0.00	0.011	0.084	0.00	0.8	0.69	92	30	0.060	4	1.5	0
TWS	ANAE	1	1	0.30	0.20	0.002	0.05	0.033	0.124	0.00	0.4	0.07	93	35	0.014	7	3.5	1
TWS	ANAE	1	2	0.86	0.25	0.000	0.00	0.011	0.065	0.03	0.8	0.05	67	21	0.019	5	2.6	0
TWS	ANAE	2	1	0.26	0.29	0.011	0.00	0.034	0.113	0.00	0.4	0.06	82	30	0.010	2	2.0	1
TWS	ANAE	2	2	0.29	0.42	0.009	0.00	0.038	0.145	0.00	0.4	0.10	118	43	0.000	6	2.7	1
TWS	ANAE	3	1	0.32	0.26	0.000	0.14	0.012	0.133	0.06	1.3	0.10	77	29	0.012	5	2.7	1
TWS	ANAE	3	2	0.48	0.20	0.000	0.19	0.014	0.134	0.13	0.8	0.12	97	37	0.024	6	2.7	1
TWS	ANAE	5	1	0.29	0.19	0.003	0.37	0.016	0.149	0.20	0.6	0.27	99	37	0.076	3	1.9	2
TWS	ANAE	5	2	0.31	0.24	0.002	0.50	0.041	0.160	0.25	0.7	0.11	91	34	0.089	4	2.1	2

APPENDIX TABLE E: CONCENTRATION OF SELECTED ELEMENTS IN DIFFERENT CHEMICAL FORMS, AND IN RICE TISSUE GROWN IN A SUSPENSION OF CHICAGO REFERENCE SOIL:DRUMMER SOIL MATERIAL.

EX	EH	SAMPLE	EH MV	REP	CU	ZN	CD	PB	CR	NI	AS	FE	MN	CA	MG	MO	SI	P	AL
												UG/G							
E	5	EIPA	-150	2	5.5	53.6	2.14	18.26	23.07	6.8	5.92	662.5	13.2	28	103	0.70	202	258	360.67
E	5	EIPA	50	1	7.5	78.4	2.04	14.30	20.12	6.9	5.28	764.8	13.2	165	128	0.56	102	232	286.78
E	5	EIPA	50	2	2.1	46.6	2.31	8.83	15.79	5.4	4.35	775.4	11.0	28	117	0.58	139	164	261.12
E	5	EIPA	250	1	17.8	58.8	2.81	18.68	23.25	7.1	5.05	656.1	19.1	81	65	0.65	92	258	304.51
E	5	EIPA	250	2	15.8	48.2	2.53	17.29	21.02	7.6	4.85	574.7	15.4	24	58	0.55	112	234	272.55
E	5	EIPA	500	1	16.4	59.5	2.47	17.40	20.08	5.8	4.47	501.9	17.1	115	52	0.53	118	219	258.96
E	5	EIPA	500	2	15.0	41.0	2.37	15.91	20.24	5.5	4.20	523.2	16.8	36	52	0.53	80	204	253.82
E	5	EACH	-150	1	1.9	72.0	6.14	3.04	0.21	6.6	1.12	244.9	57.3	3155	528	0.28	11	13	8.12
E	5	EACH	-150	2	1.2	71.5	6.06	3.25	0.29	6.9	1.12	352.0	57.3	3094	518	0.35	9	22	14.28
E	5	EACH	50	1	0.6	69.0	4.77	2.97	0.27	5.4	0.63	54.7	61.5	3480	562	0.33	9	7	14.70
E	5	EACH	50	2	0.5	55.4	2.36	2.19	0.23	5.9	0.89	308.7	53.8	2852	451	0.23	11	23	6.44
E	5	EACH	250	1	0.8	74.4	6.26	2.89	0.32	5.2	0.57	4.8	50.6	3862	918	0.24	6	17	12.52
E	5	EACH	250	2	0.8	80.2	6.37	2.45	0.37	5.4	0.86	5.0	51.7	3944	757	0.31	3	18	14.17
E	5	EACH	500	1	1.7	64.1	5.62	1.92	0.28	5.3	0.62	3.3	35.2	3516	871	0.23	5	12	11.62
E	5	EACH	500	2	1.5	73.9	5.86	1.57	0.29	5.5	0.68	7.3	36.3	3645	724	0.23	5	14	14.73
E	5	CXAL	-150	1	13.7	199.3	1.98	7.19	47.63	28.1	0.99	1289.8	50.4	38	260	1.10	29	240	707.19
E	5	CXAL	-150	2	16.9	265.3	2.83	18.10	115.37	36.4	4.16	3529.3	72.7	36	348	2.67	94	1415	1797.35
E	5	CXAL	50	1	28.0	458.2	4.31	23.58	153.79	62.0	2.79	4028.0	113.3	244	656	2.68	86	443	1471.57
E	5	CXAL	50	2	3.6	267.0	3.26	12.86	112.98	36.0	4.55	4282.8	74.4	40	426	2.77	235	1596	1838.66
E	5	CXAL	250	1	54.3	283.6	4.01	20.33	126.21	42.3	2.71	2673.5	64.0	32	273	2.44	39	1737	1787.83
E	5	CXAL	250	2	52.7	273.6	3.81	20.18	120.88	40.6	2.46	2553.1	79.3	44	268	2.33	43	1651	1713.37
E	5	CXAL	500	1	108.0	294.3	3.96	21.81	126.60	41.0	2.88	2486.8	53.6	108	266	2.38	203	1637	1772.25
E	5	CXAL	500	2	123.5	346.1	4.37	24.97	146.16	48.3	3.61	2549.6	105.4	161	290	2.80	44	1726	1998.91
E	5	RICE	-150	1	14.8	80.7	.	.	.	.	.	1919.0	554.1	8450	4882	.	.	5134	.
E	5	RICE	50	1	29.5	110.5	.	.	.	.	.	617.3	671.4	8439	4878	.	.	5649	.
E	5	RICE	250	1	31.1	114.9	.	.	.	.	.	156.5	750.5	6749	4534	.	.	4755	.
E	5	RICE	500	1	29.7	264.4	.	.	.	.	.	97.0	772.9	7141	4448	.	.	5359	.
E	5	IWS	-150	1	1.0	46.5	2.50	0.96	0.39	7.6	1.79	538.9	69.6	3758	772	0.22	310	132	10.25
E	5	IWS	-150	2	0.6	18.3	0.92	0.08	0.15	2.9	0.61	233.1	26.5	1492	428	0.04	49	47	2.77
E	5	IWS	50	1	2.5	30.2	0.41	0.98	0.40	6.6	1.96	488.3	66.0	3667	737	0.32	329	128	27.53
E	5	IWS	50	2	0.2	9.0	0.11	0.17	0.12	2.0	0.55	155.3	19.5	1146	262	0.07	49	33	3.70
E	5	IWS	250	1	0.5	41.3	2.29	0.00	0.30	4.7	0.40	13.6	54.4	4360	952	0.19	213	29	7.14
E	5	IWS	250	2	1.2	40.1	2.23	0.61	0.30	4.6	0.40	14.1	53.0	4236	927	0.19	211	28	12.93
E	5	IWS	500	1	1.5	35.5	2.01	0.92	0.28	4.7	0.23	1.7	39.7	4338	1000	0.20	190	17	11.45
E	5	IWS	500	2	1.0	33.6	1.90	0.51	0.26	4.4	0.36	1.4	37.2	4087	920	0.20	175	16	7.39

APPENDIX TABLE F: CONCENTRATION OF SELECTED ELEMENTS IN DIFFERENT CHEMICAL FORMS IN A SUSPENSION OF CHICAGO REFERENCE SLUDGE:DRUMMER SOIL MATERIAL.

EX	PH	SAMPLE	EH MV	REP	CU	ZN	CD	PB	CR	NI	AS	FE	MN	CA	MG	MO	SI	P	AL
												UG/G							
F	8	DIEA	-150	1	5.2	104.1	3.48	18.34	22.45	10.9	5.70	947.1	29.2	29	167	0.71	142	259	312.23
F	8	DIPA	-150	2	5.2	131.9	3.83	20.67	28.58	11.4	7.02	1169.4	34.0	54	224	0.92	277	301	416.94
F	8	DIPA	50	1	13.0	84.4	2.52	15.07	21.23	8.8	4.98	669.0	23.7	83	138	0.79	114	227	262.71
F	8	DIPA	50	2	15.1	100.0	2.83	16.28	23.64	10.2	5.51	818.9	26.3	27	162	0.75	256	236	322.40
F	8	DIPA	250	1	13.1	80.2	2.53	12.51	19.33	8.2	4.98	637.5	26.1	28	167	0.66	204	200	278.59
F	8	DIPA	250	2	12.9	81.4	2.44	12.36	18.89	8.1	4.76	653.9	26.9	22	165	0.64	212	191	275.95
F	8	DIPA	500	1	16.9	95.1	2.20	13.25	16.80	6.4	3.99	448.4	20.6	23	132	0.51	108	195	231.69
F	8	DIPA	500	2	16.0	92.1	2.13	14.33	17.35	6.3	4.53	453.9	19.9	23	140	0.72	214	197	256.05
F	8	EXCH	-150	1	1.2	6.0	1.15	0.04	0.25	0.6	0.56	3.0	15.6	3591	498	0.06	11	70	8.55
F	8	EXCH	-150	2	2.6	4.0	1.27	0.48	0.25	0.5	0.96	2.1	14.7	3414	470	0.13	7	70	8.47
F	8	EXCH	50	1	0.8	8.7	1.90	0.02	0.19	0.7	0.67	3.6	17.1	3438	685	0.06	1	36	7.20
F	8	EXCH	50	2	1.4	12.0	2.04	0.20	0.26	0.7	0.86	2.4	17.6	3555	570	0.09	4	36	11.88
F	8	EXCH	250	1	2.3	3.5	1.86	0.56	0.22	0.7	0.70	2.9	10.0	3552	476	0.09	2	87	6.29
F	8	EXCH	250	2	1.2	5.1	1.90	0.29	0.24	0.7	0.38	2.2	10.0	3559	548	0.07	3	84	9.34
F	8	EXCH	500	1	1.4	7.6	1.77	0.70	0.29	0.7	0.78	2.5	5.7	3045	461	0.17	5	31	11.41
F	8	EXCH	500	2	1.2	5.2	1.77	0.00	0.22	0.8	0.32	2.5	5.6	3051	462	0.05	3	32	6.99
F	8	OXAL	-150	1	13.1	282.6	3.88	16.58	116.71	40.7	4.66	3149.1	116.6	64	592	2.18	66	1441	1629.09
F	8	OXAL	-150	2	11.0	291.4	3.59	15.01	115.80	40.1	4.80	3280.2	114.3	71	604	2.16	183	1445	1657.69
F	8	OXAL	50	1	39.8	278.3	3.71	15.08	132.70	43.0	4.18	2870.7	110.6	36	560	2.26	212	1783	1744.77
F	8	OXAL	50	2	40.8	285.8	3.65	14.99	135.27	43.9	4.39	2848.8	107.8	55	587	2.31	223	1778	1790.40
F	8	OXAL	250	1	73.4	249.7	2.90	8.57	101.82	34.0	1.90	1677.9	69.1	92	560	1.18	64	372	870.95
F	8	OXAL	250	2	89.9	273.5	3.74	12.49	128.03	41.6	3.83	2685.1	112.9	58	591	2.07	51	1658	1676.47
F	8	OXAL	500	1	73.3	153.9	2.18	9.64	69.13	24.4	2.02	1521.7	83.9	62	409	1.12	42	643	822.70
F	8	OXAL	500	2	71.7	146.1	2.14	7.28	71.54	24.3	2.31	1626.2	84.8	36	403	1.23	65	872	963.75
F	8	TWS	-150	1	1.1	1.6	0.27	0.56	0.75	1.3	0.71	30.4	0.7	172	31	0.98	11	55	10.38
F	8	TWS	-150	2	2.0	2.6	0.26	0.33	0.65	1.1	0.24	28.7	0.6	167	30	0.86	45	53	32.19
F	8	TWS	50	1	0.6	1.5	0.06	0.42	0.28	0.8	0.61	10.1	0.6	239	57	0.91	10	24	4.85
F	8	TWS	50	2	0.9	1.2	0.08	0.25	0.24	0.7	0.57	9.5	0.6	246	59	0.90	9	25	3.88
F	8	TWS	250	1	3.1	1.6	0.12	0.47	0.71	1.2	0.97	28.4	0.5	187	42	1.05	29	49	15.54
F	8	TWS	250	2	3.3	13.1	0.13	0.80	0.67	1.0	1.04	24.8	0.5	177	30	1.05	16	48	16.33
F	8	TWS	500	1	1.4	1.5	0.08	0.00	0.30	0.5	0.10	7.7	0.3	220	52	0.78	35	20	9.41
F	8	TWS	500	2	1.0	0.5	0.06	0.00	0.26	0.5	0.18	6.0	0.2	198	41	0.72	34	19	5.86

APPENDIX TABLE G1: LEVELS OF SELECTED ELEMENTS IN HUMIC, FULVIC, AND PRECIPITATE FORMS OF BATON ROUGE SLUDGE PROCESSED BY AEROBIC OR ANAEROBIC DIGESTION METHODS.

FORM	TREAT	REP	CU	ZN	CD	FE	CR	NI	AS	PB	MN	CA	MG	SI	P	AL	PCT
										UG/G							
FUL	AERC	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	20.4
FUL	AERC	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	20.1
FUL	ANAE	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	20.7
FUL	ANAE	2	14.6	7	0.106	0.9	0.15	4.91	1.6	42	2.1	146	0.3	472	408	16	21.2
HUM	AERC	1	9.4	13	0.000	0.1	0.69	0.59	1.5	32	0.2	7	2.3	80	249	67	5.1
HUM	AERC	2	10.5	12	0.000	0.4	0.74	0.52	1.5	30	0.2	7	2.2	82	227	56	4.7
HUM	ANAE	1	13.3	22	0.107	6.2	0.56	0.88	4.3	38	0.4	17	1.7	97	316	82	6.2
HUM	ANAE	2	12.0	16	0.064	3.5	0.79	0.48	2.6	27	0.3	11	1.5	83	240	59	5.6
PPT	AERC	1	1.2	35	0.075	8.9	1.35	0.69	15.7	243	3.7	65	1.1	60	1811	1368	2.0
PPT	AERC	2	1.6	40	0.082	11.8	2.00	0.98	19.5	315	4.3	76	1.4	66	2242	1687	2.0
PPT	ANAE	1	0.7	51	0.077	11.4	2.30	0.68	16.1	241	4.7	115	1.2	55	1996	1402	2.4
PPT	ANAE	2	0.3	51	0.071	12.3	2.23	0.75	15.8	327	4.6	105	1.2	46	2032	1303	2.5

APPENDIX TABLE G2. THE CONCENTRATION OF SELECTED ELEMENTS IN HUMIC, FULVIC AND PRECIPITATE FRACTIONS EXTRACTED FROM SLUDGE-SOIL MIXTURES INCUBATED UNDER CONTROLLED PH AND REDOX POTENTIAL CONDITIONS.

FCRM	REP	PH	EH MV	OESER	CU	ZN	CD	PB	CR	NI	AS	FE	MN	CA	MG	SI	P	AL	AMOUNT %
											UG/G								
FUL	1	5.0	-150	17A	2.4	9.7	.239	1.46	0.33	6.26	2.10	9.3	0.58	46.4	0.62	61.5	24	60	13.15
FUL	2	5.0	-150	17B	2.3	12.1	.630	3.01	0.38	6.44	2.94	12.1	0.85	50.5	0.75	207.0	20	64	14.58
FUL	1	5.0	250	15A	4.1	2.8	.175	3.73	0.37	5.51	2.38	4.0	0.80	81.8	0.79	104.5	14	48	12.65
FUL	2	5.0	250	15B	8.8	1.9	.202	3.74	0.44	6.07	2.71	11.9	0.86	72.4	0.89	136.0	18	59	13.18
FUL	1	5.0	250	27A	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
FUL	2	5.0	250	27B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
FUL	1	5.0	50	16A	4.9	14.0	.198	0.00	0.14	7.42	0.65	14.9	1.58	80.2	0.38	169.9	19	47	13.51
FUL	2	5.0	50	16B	2.0	10.9	.116	1.81	0.41	7.23	1.30	9.7	1.06	58.6	0.51	21.8	13	45	13.67
FUL	1	5.0	50	28A	18.3	6.7	.255	0.58	0.20	7.44	0.81	4.5	1.26	58.3	0.46	15.8	35	94	14.30
FUL	2	5.0	50	28B	17.2	6.3	.294	0.41	0.14	7.29	0.94	3.4	1.02	56.6	0.47	15.2	28	74	14.10
FUL	1	5.0	500	14A	8.3	1.0	.080	0.65	0.26	3.48	0.00	4.3	0.83	71.4	0.45	96.0	12	26	13.66
FUL	2	5.0	500	14B	13.4	4.1	.144	1.26	0.38	5.05	0.60	3.8	0.86	76.7	0.55	132.4	16	43	13.74
FUL	1	5.0	500	26A	13.5	2.0	.259	2.26	0.34	5.86	2.37	6.8	0.97	70.3	0.56	247.9	25	55	14.37
FUL	2	5.0	500	26B	19.7	2.1	.382	1.67	0.61	6.49	2.46	7.7	0.85	78.1	0.58	277.3	33	126	14.33
FUL	1	6.5	-150	21A	10.8	3.6	.146	0.86	0.66	15.44	0.46	11.3	1.58	57.4	0.43	562.9	397	56	15.27
FUL	2	6.5	-150	21B	16.5	5.8	.382	1.37	1.06	14.07	4.62	12.1	1.63	67.8	0.44	612.4	488	83	14.24
FUL	1	6.5	-150	7-A	7.9	7.2	.208	2.07	0.40	6.97	2.85	32.5	1.38	69.9	0.55	351.1	34	103	10.67
FUL	2	6.5	-150	7-B	11.3	12.3	.304	2.98	0.90	11.29	4.42	32.7	13.81	129.3	0.58	483.7	59	155	14.65
FUL	1	6.5	250	19A	13.6	9.4	.606	1.83	0.44	8.69	2.13	7.8	1.29	74.5	0.48	193.4	29	109	13.32
FUL	2	6.5	250	19B	22.0	13.0	.695	4.24	0.54	11.30	6.07	8.5	1.47	89.9	0.76	405.9	64	342	14.27
FUL	1	6.5	250	5-A	11.9	4.6	.339	1.66	0.71	5.93	1.06	4.7	0.74	68.8	0.52	256.3	19	49	13.71
FUL	2	6.5	250	5-B	9.4	7.5	.676	1.60	0.29	6.85	2.21	3.8	1.06	81.3	0.36	481.3	25	68	12.89
FUL	1	6.5	50	20A	5.8	7.8	.198	2.30	0.51	8.49	3.81	8.4	2.71	76.3	0.66	465.9	31	124	15.04
FUL	2	6.5	50	20B	11.0	8.3	.353	3.08	0.63	11.20	4.93	11.2	4.45	96.8	0.68	513.6	54	198	14.68
FUL	1	6.5	50	6-A	6.7	5.6	.275	1.36	0.30	5.70	2.41	4.4	0.75	51.4	0.20	304.8	31	79	15.70
FUL	2	6.5	50	6-B	6.6	6.3	.424	1.00	0.30	5.94	2.37	4.1	0.72	56.2	0.16	261.5	29	73	15.42
FUL	1	6.5	500	18A	15.0	10.5	.677	3.41	0.45	10.05	2.85	6.4	2.04	56.0	0.65	43.4	25	58	13.56
FUL	2	6.5	500	18B	18.4	7.9	.694	3.76	0.59	9.44	2.87	12.1	1.66	71.1	0.69	431.4	28	85	13.97
FUL	1	6.5	500	4-A	16.4	6.1	.490	1.31	0.54	6.62	0.75	4.6	0.77	67.2	0.30	302.9	19	49	15.94
FUL	2	6.5	500	4-B	17.0	8.5	.667	0.00	0.17	6.88	0.85	3.3	0.81	49.6	0.04	260.2	16	56	14.91
FUL	1	8.0	-150	11A	14.3	9.1	.003	0.36	0.45	4.72	2.24	2.9	0.67	56.5	0.31	436.4	28	108	15.10
FUL	2	8.0	-150	11B	17.9	7.0	.206	2.07	0.59	5.46	2.55	4.8	0.69	62.6	0.61	145.6	30	111	16.51
FUL	1	8.0	-150	25A	8.9	7.5	.157	1.48	0.40	5.41	2.18	7.2	0.88	56.9	0.65	290.8	33	99	13.89
FUL	2	8.0	-150	25B	9.0	7.9	.225	1.66	0.41	4.70	2.11	5.5	0.75	59.8	0.51	285.1	31	96	13.49
FUL	1	8.0	250	23A	19.0	10.3	.516	2.12	0.51	6.23	1.61	6.3	1.26	65.7	0.54	322.9	28	80	17.10
FUL	2	8.0	250	23B	12.7	9.7	.406	1.23	0.37	5.19	1.12	4.3	0.81	55.7	0.35	333.2	20	69	15.40
FUL	1	8.0	250	30A	13.1	8.3	.544	0.00	0.14	4.46	0.48	4.4	0.66	46.3	0.24	41.5	23	59	13.89
FUL	2	8.0	250	30B	15.0	9.6	.676	0.00	0.28	5.78	0.80	3.1	1.18	58.6	0.33	25.8	24	79	13.56
FUL	1	8.0	250	9-A	13.3	5.9	.142	0.20	0.27	3.78	1.43	2.5	0.84	54.6	0.20	250.9	19	60	17.75
FUL	2	8.0	250	9-B	12.3	6.0	.180	0.91	0.14	3.99	1.70	2.9	0.55	53.4	0.41	235.7	19	62	15.39
FUL	1	8.0	50	10A	10.4	9.5	.259	1.73	0.32	5.31	1.41	3.7	0.79	54.3	0.51	141.4	29	82	14.65
FUL	2	8.0	50	10B	8.6	7.4	.116	0.25	0.16	4.82	0.74	2.8	0.74	51.2	0.25	279.5	18	66	14.81
FUL	1	8.0	50	24A	11.3	9.3	.150	1.25	0.26	6.46	1.68	5.2	0.87	55.9	0.44	360.0	26	95	17.62
FUL	2	8.0	50	24B	15.9	10.5	.163	1.85	0.55	8.30	2.10	6.4	0.88	61.5	0.51	321.4	26	98	16.79
FUL	1	8.0	50	31A	13.9	9.2	.321	0.00	0.21	4.68	0.74	2.5	1.17	51.5	0.28	35.3	22	81	13.86
FUL	2	8.0	50	31B	15.6	13.9	.413	0.61	0.26	5.51	0.43	3.3	0.55	69.3	0.43	32.7	30	94	15.49
FUL	1	8.0	500	22A	12.1	9.7	.351	1.13	0.29	4.64	1.65	4.0	0.73	50.8	0.34	247.8	19	55	13.17
FUL	2	8.0	500	22B	14.1	8.9	.429	1.80	0.28	5.09	1.15	4.5	0.79	49.5	0.44	234.5	17	56	13.54
FUL	1	8.0	500	29A	1.4	0.6	.054	0.02	0.02	0.36	0.02	0.9	0.26	0.3	0.40	1.4	13	9	0.31
FUL	2	8.0	500	29B	19.6	9.9	.743	0.00	0.25	6.10	0.44	3.0	1.26	71.8	0.22	27.1	36	110	13.59
FUL	1	8.0	500	8-A	15.2	9.9	.406	0.39	0.25	4.02	1.82	10.4	0.75	50.7	0.28	384.3	34	94	19.34
FUL	2	8.0	500	8-B	16.7	6.7	.191	0.66	0.28	4.88	2.45	5.3	1.10	55.8	0.44	330.9	36	90	19.14

APPENDIX TABLE G2. THE CONCENTRATION OF SELECTED ELEMENTS IN HUMIC, FULVIC AND PRECIPITATE FRACTIONS EXTRACTED FROM SLUDGE-SOIL MIXTURES INCUBATED UNDER CONTROLLED PH AND REDOX POTENTIAL CONDITIONS.

FCTN	REP	PH	EH MV	OBSER	CU	ZN	CD	PB	CR	NI	AS	FE	MN	CA	MG	SI	P	AL	AMOUNT %
											UG/G								
HUM	1	5.0	-150	17A	2.2	0.4	.001	0.05	0.03	0.06	0.05	4.1	0.15	0.2	0.08	2.4	3	2	0.13
HUM	2	5.0	-150	17B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HUM	1	5.0	250	15A	6.7	0.1	.005	0.10	0.03	0.11	0.08	4.0	0.13	0.6	0.15	1.6	2	3	0.20
HUM	2	5.0	250	15B	6.5	0.1	.003	0.05	0.05	0.09	0.04	4.1	0.11	0.5	0.14	1.7	2	3	0.20
HUM	1	5.0	250	27A	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HUM	2	5.0	250	27B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
HUM	1	5.0	50	16A	6.8	1.7	.004	0.06	0.09	0.19	0.11	8.7	0.38	2.3	0.26	6.5	7	8	0.40
HUM	2	5.0	50	16B	5.3	1.5	.000	0.05	0.06	0.15	0.09	6.2	0.19	0.5	0.22	3.5	5	5	0.31
HUM	1	5.0	50	28A	13.3	0.5	.001	0.00	0.11	0.16	0.00	10.1	0.35	0.3	0.44	0.5	9	10	0.31
HUM	2	5.0	50	28B	12.7	0.4	.002	0.06	0.11	0.18	0.06	9.1	0.32	0.6	0.50	1.0	8	9	0.30
HUM	1	5.0	500	14A	5.1	0.0	.001	0.03	0.03	0.05	0.01	2.9	0.06	0.6	0.08	0.7	1	2	0.19
HUM	2	5.0	500	14B	7.6	0.1	.005	0.04	0.06	0.09	0.03	4.3	0.68	0.5	0.17	1.2	2	3	0.26
HUM	1	5.0	500	26A	7.3	0.1	.021	0.08	0.04	0.08	0.07	4.4	0.05	0.6	0.20	1.7	4	3	0.26
HUM	2	5.0	500	26B	7.9	0.0	.004	0.04	0.12	0.07	0.06	4.5	0.07	0.4	0.21	1.4	4	3	0.28
HUM	1	6.5	-150	21A	4.6	0.7	.005	0.03	0.24	0.42	0.21	4.6	0.13	0.8	0.29	4.5	13	5	0.70
HUM	2	6.5	-150	21B	6.4	0.4	.006	0.06	0.27	0.28	0.17	4.3	0.11	0.7	0.25	3.7	10	4	0.75
HUM	1	6.5	-150	7-A	10.7	1.5	.014	0.44	0.11	0.17	0.20	9.2	0.32	0.6	0.43	8.5	12	10	0.30
HUM	2	6.5	-150	7-B	12.0	1.8	.030	0.19	0.10	0.21	0.19	10.6	0.27	0.8	0.43	6.9	14	9	0.30
HUM	1	6.5	250	19A	8.3	0.4	.009	0.12	0.10	0.21	0.16	6.9	0.45	0.7	0.24	5.6	10	9	0.52
HUM	2	6.5	250	19B	8.3	0.4	.013	0.11	0.12	0.20	0.18	6.7	0.25	1.0	0.25	5.7	11	9	0.51
HUM	1	6.5	250	5-A	16.4	0.3	.020	0.14	0.20	0.12	0.13	10.2	0.18	0.5	0.44	5.7	11	8	0.33
HUM	2	6.5	250	5-B	22.1	1.5	.020	0.20	0.44	0.36	0.25	15.1	0.32	1.2	0.51	12.6	27	16	0.53
HUM	1	6.5	50	20A	5.7	0.7	.126	0.11	0.09	0.18	0.20	8.7	0.57	0.6	0.25	11.3	9	10	0.43
HUM	2	6.5	50	20B	8.2	0.4	.075	0.16	0.12	0.27	0.24	8.4	0.48	1.0	0.28	10.4	12	11	0.56
HUM	1	6.5	50	6-A	23.1	3.0	.018	0.38	0.20	0.42	0.31	18.0	0.27	1.5	0.68	12.7	25	16	0.62
HUM	2	6.5	50	6-B	17.6	0.8	.108	0.16	0.16	0.28	0.20	12.1	0.18	0.9	0.51	9.5	17	10	0.40
HUM	1	6.5	500	18A	8.9	0.3	.022	0.15	0.11	0.20	0.23	7.4	0.41	1.4	0.26	9.0	12	10	0.55
HUM	2	6.5	500	18B	10.4	0.3	.028	0.22	0.16	0.26	0.29	8.6	0.51	1.1	0.28	10.1	14	12	0.60
HUM	1	6.5	500	4-A	17.0	0.2	.003	0.08	0.17	0.09	0.14	9.2	0.20	0.5	0.45	7.1	14	8	0.33
HUM	2	6.5	500	4-B	19.3	0.4	.006	0.06	0.14	0.25	0.16	12.6	0.34	1.5	0.44	11.7	24	13	0.43
HUM	1	8.0	-150	11A	17.0	0.3	.015	0.09	0.17	0.16	0.17	12.1	0.43	0.7	0.35	10.4	8	10	0.26
HUM	2	8.0	-150	11B	14.6	0.4	.017	0.08	0.17	0.16	0.14	9.1	0.31	0.8	0.28	8.1	7	8	0.26
HUM	1	8.0	-150	25A	7.4	0.7	.013	0.06	0.04	0.10	0.08	5.3	0.10	0.4	0.22	2.7	4	4	0.29
HUM	2	8.0	-150	25B	7.5	0.3	.009	0.05	0.05	0.09	0.07	4.6	0.08	0.4	0.22	1.8	3	3	0.26
HUM	1	8.0	250	23A	8.4	0.2	.005	0.06	0.13	0.10	0.07	4.8	0.15	0.4	0.19	3.0	5	5	0.39
HUM	2	8.0	250	23B	5.8	0.2	.003	0.06	0.08	0.07	0.06	4.1	0.13	0.4	0.19	2.0	4	4	0.34
HUM	1	8.0	250	30A	11.3	0.6	.008	0.00	0.13	0.13	0.01	8.2	0.38	0.2	0.46	0.8	12	8	0.38
HUM	2	8.0	250	30B	12.5	0.4	.010	0.00	0.19	0.17	0.05	9.2	0.48	0.6	0.53	0.8	15	11	0.40
HUM	1	8.0	250	9-A	21.3	1.2	.010	0.12	0.19	0.26	0.27	14.3	0.41	1.4	0.84	12.1	16	16	0.45
HUM	2	8.0	250	9-B	12.1	0.6	.007	0.04	0.11	0.15	0.14	8.5	0.26	0.8	0.38	8.3	9	9	0.32
HUM	1	8.0	50	10A	15.7	0.7	.015	0.06	0.11	0.15	0.13	11.5	0.40	0.4	0.30	7.4	9	9	0.24
HUM	2	8.0	50	10B	10.0	0.6	.012	0.05	0.07	0.12	0.08	7.6	0.22	0.5	0.24	4.7	7	7	0.22
HUM	1	8.0	50	24A	7.0	0.3	.011	0.04	0.05	0.10	0.07	5.0	0.16	0.4	0.21	2.9	4	4	0.32
HUM	2	8.0	50	24B	6.8	0.2	.015	0.05	0.08	0.08	0.06	4.3	0.12	0.5	0.20	2.5	3	3	0.29
HUM	1	8.0	50	31A	13.7	0.6	.007	0.00	0.14	0.16	0.06	9.5	0.33	0.4	0.53	1.2	14	10	0.41
HUM	2	8.0	50	31B	14.9	0.5	.006	0.00	0.17	0.18	0.08	9.4	0.34	2.0	0.60	0.8	13	10	0.40
HUM	1	8.0	500	22A	8.4	0.4	.004	0.07	0.13	0.11	0.11	6.1	0.19	0.5	0.22	3.8	8	6	0.36
HUM	2	8.0	500	22B	7.3	0.3	.001	0.05	0.08	0.08	0.08	5.3	0.16	0.3	0.19	3.0	7	5	0.35
HUM	1	8.0	500	29A	161.7	7.3	.093	0.00	1.76	2.00	0.80	3.6	0.88	54.2	0.36	23.1	38	91	13.27
HUM	2	8.0	500	29B	12.7	0.4	.006	0.00	0.01	0.18	0.04	9.4	0.48	0.5	0.44	0.8	15	11	0.39
HUM	1	8.0	500	8-A	23.4	0.5	.001	0.06	0.22	0.22	0.19	14.9	0.33	1.1	0.49	10.9	15	12	0.49
HUM	2	8.0	500	8-B	28.3	0.5	.001	0.09	0.28	0.26	0.17	18.7	0.47	1.2	0.57	15.3	18	14	0.53

APPENDIX TABLE G2. THE CONCENTRATION OF SELECTED ELEMENTS IN HUMIC, FULVIC AND PRECIPITATE FRACTIONS EXTRACTED FROM SLUDGE-SOIL MIXTURES INCUBATED UNDER CONTROLLED PH AND REDOX POTENTIAL CONDITIONS.

PCBs	REP	PH	Eh MV	OBSERV	CU	ZN	CD	FE	CR	NI	AS	PB	MN	CA	MO	SI	P	AL	AMOUNT %
					UG/G														
PET	1	5.0	-150	17A	0.8	3.0	.013	1.33	0.25	1.11	3.31	12.3	0.05	2.5	0.23	22.9	87	225	0.71
PET	2	5.0	-150	17B	0.6	1.7	.009	1.11	0.15	0.70	2.79	9.3	0.06	1.7	0.21	13.0	69	185	0.62
PET	1	5.0	250	15A	1.4	0.3	.005	0.82	0.19	0.64	2.01	1.9	0.04	1.3	0.15	8.9	25	143	0.47
PET	2	5.0	250	15B	1.9	0.2	.004	0.63	0.32	0.42	1.39	1.3	0.02	1.1	0.09	9.0	16	99	0.36
PET	1	5.0	250	27A	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
PET	2	5.0	250	27B	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
PET	1	5.0	50	16A	4.1	1.2	.011	1.31	0.34	0.93	3.17	6.7	0.05	1.4	0.25	12.2	64	233	0.75
PET	2	5.0	50	16B	1.0	1.1	.007	1.05	0.21	0.79	2.57	6.0	0.04	1.1	0.19	12.5	49	187	0.72
PET	1	5.0	50	28A	2.0	1.4	.011	0.37	0.14	0.57	0.27	3.2	0.02	1.6	0.11	0.8	30	135	0.31
PET	2	5.0	50	28B	5.8	3.2	.029	0.93	0.31	1.58	0.71	7.9	0.05	4.1	0.29	1.5	70	350	0.44
PET	1	5.0	500	14A	1.7	0.2	.007	0.53	0.20	0.24	1.12	1.0	0.03	1.3	0.07	11.2	11	74	0.32
PET	2	5.0	500	14B	3.3	0.2	.006	0.61	0.32	0.32	1.45	1.3	0.03	1.3	0.10	8.3	17	95	0.39
PET	1	5.0	500	26A	2.7	0.2	.005	0.63	0.16	0.43	1.47	1.4	0.02	1.4	0.10	13.5	18	103	0.36
PET	2	5.0	500	26B	2.4	0.2	.008	0.59	0.38	0.35	1.20	1.2	0.02	1.4	0.08	13.0	15	81	0.31
PET	1	6.5	-150	21A	0.5	4.1	.033	0.93	0.66	0.80	1.95	15.9	0.08	12.1	0.12	15.7	196	155	0.54
PET	2	6.5	-150	21B	1.1	3.6	.031	1.04	0.74	0.78	1.55	13.6	0.06	8.9	0.10	4.8	163	122	0.47
PET	1	6.5	-150	7-A	2.0	1.8	.020	1.82	0.46	1.36	4.30	8.8	0.04	2.8	0.32	29.7	103	345	0.47
PET	2	6.5	-150	7-B	2.5	2.5	.027	2.26	0.57	1.53	5.25	10.7	0.04	3.8	0.50	33.3	120	374	0.42
PET	1	6.5	250	19A	7.3	3.1	.	0.60	0.42	1.80	0.54	6.8	0.05	3.6	0.32	7.5	84	366	0.67
PET	2	6.5	250	19B	3.2	0.4	.013	0.64	0.23	0.45	1.64	2.8	0.05	1.4	0.13	13.7	32	115	0.56
PET	1	6.5	250	5-A	8.8	2.4	.039	2.90	1.04	1.72	6.36	7.0	0.07	4.6	0.45	50.3	96	448	0.60
PET	2	6.5	250	5-B	12.3	5.7	.106	4.33	1.42	3.39	9.95	15.8	0.07	7.2	0.67	77.3	210	714	1.10
PET	1	6.5	50	20A	1.5	0.8	.015	1.17	0.25	0.97	2.92	3.8	0.06	2.1	0.21	30.5	45	186	0.62
PET	2	6.5	50	20B	2.3	1.2	.019	1.13	0.38	1.20	3.05	4.4	0.08	3.3	0.20	38.4	57	209	0.66
PET	1	6.5	50	6-A	4.0	4.7	.065	3.45	0.77	2.60	7.97	13.2	0.07	6.3	0.53	46.8	107	565	0.99
PET	2	6.5	50	6-B	3.6	3.9	.047	2.80	0.71	2.13	6.64	11.5	0.04	4.8	0.43	47.6	144	477	0.71
PET	1	6.5	500	18A	6.3	0.4	.019	0.92	0.27	0.64	2.57	3.1	0.04	1.4	0.19	18.2	55	179	0.70
PET	2	6.5	500	18B	7.0	0.8	.023	1.24	0.45	0.95	2.98	4.2	0.06	2.5	0.21	32.6	60	209	0.80
PET	1	6.5	560	4-A	9.4	1.4	.023	1.99	0.83	1.09	4.59	5.1	0.03	2.4	0.34	37.5	77	324	0.57
PET	2	6.5	500	4-B	11.2	2.1	.035	2.45	0.68	1.59	5.58	8.6	0.04	3.0	0.43	47.7	127	436	0.77
PET	1	8.0	-150	11A	4.2	1.6	.009	1.43	0.62	0.77	2.99	3.2	0.03	2.7	0.23	16.3	57	224	0.40
PET	2	8.0	-150	11B	5.3	1.7	.010	1.56	0.81	0.84	3.25	3.5	0.03	2.9	0.23	12.8	62	243	0.42
PET	1	8.0	-150	25A	1.2	1.2	.010	0.78	0.18	0.41	1.73	1.8	0.02	1.6	0.12	19.2	30	121	0.38
PET	2	8.0	-150	25B	1.3	1.2	.010	0.78	0.22	0.38	1.56	1.6	0.04	1.6	0.11	17.0	28	107	0.36
PET	1	8.0	250	23A	4.9	1.4	.015	1.00	0.66	0.58	2.30	3.0	0.03	1.7	0.15	19.5	42	158	0.57
PET	2	8.0	250	23B	3.8	1.3	.012	0.94	0.39	0.52	2.20	2.7	0.02	1.4	0.14	25.6	39	151	0.55
PET	1	8.0	250	30A	5.0	4.2	.030	0.67	0.34	0.75	0.48	4.6	0.04	2.2	0.20	1.0	70	227	0.34
PET	2	8.0	250	30B	8.2	1.9	.034	0.76	0.52	0.98	0.61	6.4	0.05	2.6	0.28	1.9	98	299	0.48
PET	1	8.0	250	9-A	7.8	3.6	.032	2.52	0.72	1.32	6.04	4.9	0.05	4.7	0.37	31.2	93	417	0.67
PET	2	8.0	250	9-B	4.4	2.2	.018	1.33	0.35	0.74	3.26	2.5	0.05	2.7	0.21	8.8	52	231	0.44
PET	1	8.0	50	10A	2.3	2.7	.025	1.58	0.43	0.97	3.28	4.1	0.03	3.6	0.24	31.9	61	257	0.42
PET	2	8.0	50	10B	3.4	2.5	.014	1.79	0.46	1.15	4.14	5.2	0.04	4.7	0.31	41.2	84	315	0.51
PET	1	8.0	50	24A	2.9	1.1	.007	0.98	0.25	0.86	2.29	2.6	0.03	1.6	0.17	28.0	41	169	0.62
PET	2	8.0	50	24B	3.4	0.9	.006	0.90	0.41	0.45	1.87	2.3	0.03	1.5	0.13	18.4	34	133	0.54
PET	1	8.0	50	31A	6.5	2.1	.024	0.90	0.47	0.89	0.69	6.4	0.04	2.7	0.30	2.8	97	299	0.51
PET	2	8.0	50	31B	7.1	2.4	.028	1.04	0.54	1.03	0.65	6.7	0.03	3.2	0.31	3.6	108	328	0.58
PET	1	8.0	500	22A	4.3	1.1	.015	0.96	0.39	0.45	2.15	2.3	0.04	1.4	0.15	12.0	40	143	0.54
PET	2	8.0	500	22B	4.3	1.7	.017	1.07	0.26	0.60	2.42	2.8	0.03	1.7	0.16	20.4	42	166	0.57
PET	1	8.0	500	29A	4.3	1.5	.028	0.54	0.32	0.58	0.37	3.7	0.03	2.5	0.16	0.8	61	170	0.29
PET	2	8.0	500	29B	7.4	1.4	.033	0.57	0.42	0.84	0.47	4.9	0.04	2.5	0.21	1.9	82	234	0.44
PET	1	8.0	500	8-A	0.8	0.3	.000	0.21	0.04	0.08	0.33	0.5	0.00	0.1	0.01	2.9	3	31	0.69
PET	2	8.0	560	8-B	7.2	2.2	.024	2.15	0.64	1.05	5.38	5.3	0.05	4.1	0.30	33.8	126	371	0.74

APPENDIX TABLE 1: CONCENTRATION OF SELECTED ELEMENTS IN DIFFERENT CHEMICAL FORMS, AND IN CORN TISSUE GROWN IN A SUSPENSION OF CHICAGO REFERENCE SLUDGE:DRUMMER SOIL MATERIAL.

EX	EB	SAMPLE	EB MV	REP	CU	ZN	CD	PB	CR	NI	AS	FE	MN	CA	MG	MO	SE	P	AL
												UG/G							
1	.	EIBK	.	1	14.2	5.1	1.91	19.81	6.23	4.7	6.82	47.2	1.8	396	2	3.14	21	29	88.71
1	.	CCBN	.	1	17.1	110.3	1.54	13.67	26.96	10.8	7.65	206.6	102.2	3455	102	3.37	92	11970	64.54
1	7	CCBN	-150	1	25.2	102.7	2.69	17.42	30.08	16.6	9.70	174.5	181.9	5548	182	3.99	80	7558	108.50
1	7	CCBN	50	1	22.3	163.8	6.18	41.65	11.75	22.6	8.64	240.4	166.3	10E3	166	6.41	105	10590	192.70
1	7	CCBN	250	1	28.8	489.2	23.91	14.41	37.05	19.7	6.78	281.5	165.7	11E3	166	6.49	60	10050	120.50
1	7	CCBN	500	1	42.1	925.8	110.40	15.26	13.75	19.9	6.36	315.9	358.4	11E3	358	7.96	108	11330	151.20
1	7	DIPA	-150	1	3.7	109.2	1.79	22.57	24.48	11.6	5.53	648.5	16.2	42	135	0.58	227	245	337.27
1	7	DIPA	-150	2	3.1	78.1	1.53	17.19	24.19	8.9	5.18	606.0	14.8	19	140	0.56	164	230	315.12
1	7	DIPA	50	1	11.8	74.9	2.15	14.70	41.45	8.3	5.15	776.7	19.2	28	130	0.50	168	225	287.81
1	7	DIPA	50	2	12.1	76.5	2.17	15.74	22.11	8.5	5.34	812.0	20.1	136	1	231	244	320	.
1	7	DIPA	250	1	19.5	61.5	2.69	17.30	24.11	7.6	4.74	515.4	19.5	23	123	0.48	216	249	298.65
1	7	DIPA	250	2	19.9	54.7	3.06	18.06	23.69	6.8	4.37	513.0	19.1	24	125	0.46	203	235	291.44
1	7	DIPA	500	1	18.9	49.4	1.58	15.58	22.88	6.2	2.76	507.6	18.0	24	113	0.53	156	209	262.15
1	7	DIPA	500	2	21.1	58.6	2.48	17.65	22.73	6.9	4.26	500.5	18.8	67	110	0.44	198	238	265.65
1	7	EXCH	-150	1	3.6	1.0	0.00	0.10	0.16	1.9	0.00	93.7	51.5	3962	530	0.23	133	8	22.45
1	7	EXCH	-150	2	4.4	0.8	0.00	0.00	0.19	2.7	0.00	445.4	83.0	3761	588	0.19	174	62	23.10
1	7	EXCH	50	1	0.8	12.9	2.94	0.11	0.11	1.0	0.00	1.6	34.7	3443	685	0.12	53	25	7.89
1	7	EXCH	50	2	0.6	11.8	2.98	0.42	0.19	1.2	0.00	2.1	34.8	3449	681	0.15	45	26	8.58
1	7	EXCH	250	1	2.0	18.2	3.55	0.05	0.14	1.9	0.00	1.1	30.1	3279	636	0.12	72	12	9.51
1	7	EXCH	250	2	1.8	18.8	3.50	0.19	0.16	1.9	0.00	1.5	29.6	3237	632	0.12	126	13	23.42
1	7	EXCH	500	1	2.0	21.0	3.96	0.16	0.17	2.4	0.15	1.0	25.5	3569	713	0.11	131	16	21.16
1	7	EXCH	500	2	2.9	20.9	3.55	0.00	0.15	2.2	0.00	0.9	24.0	3376	689	0.07	47	15	5.35
1	7	CXAL	-150	1	1.4	331.3	0.49	19.92	135.27	46.0	23.44	4714.0	92.1	30	534	4.60	207	1765	1889.75
1	7	CXAL	-150	2	0.7	285.9	0.34	16.73	125.74	40.2	21.34	4544.9	89.5	24	513	2.36	191	1655	1733.63
1	7	CXAL	50	1	31.1	324.9	3.20	25.20	125.06	44.9	24.25	3176.8	105.3	47	604	2.34	117	1727	1766.68
1	7	CXAL	50	2	27.7	306.9	3.06	24.33	117.34	42.4	23.53	3043.6	104.4	29	576	2.45	231	1634	1693.98
1	7	CXAL	250	1	90.3	465.8	2.88	22.26	119.87	39.8	20.62	2604.7	93.9	26	499	2.12	205	1606	1634.80
1	7	CXAL	250	2	91.5	267.8	3.63	22.80	116.45	39.7	19.15	2420.1	94.4	48	517	2.05	175	1608	1528.85
1	7	CXAL	500	1	110.1	285.3	4.97	25.14	131.18	44.4	22.56	2801.3	106.7	30	609	2.32	112	1774	1752.71
1	7	CXAL	500	2	110.9	281.3	5.25	25.81	123.04	41.0	21.19	2653.5	106.1	21	529	2.19	213	1692	1733.53
1	7	IWS	-150	1	0.0	0.3	0.00	0.00	0.13	1.1	0.24	101.7	13.8	1159	303	0.30	120	50	2.95
1	7	IWS	-150	2	0.2	0.5	0.02	0.20	0.14	1.1	0.27	101.4	13.4	1173	292	0.33	110	45	5.96
1	7	IWS	50	1	0.1	0.9	0.09	0.00	0.09	0.6	0.17	1.1	7.4	1113	290	0.49	74	14	3.66
1	7	IWS	50	2	0.0	0.7	0.07	0.00	0.09	0.6	0.11	0.9	7.4	1113	289	0.49	77	12	3.51
1	7	IWS	250	1	0.1	1.3	0.13	0.00	0.07	0.6	0.00	0.3	8.4	1272	303	0.37	49	5	3.30
1	7	IWS	250	2	0.1	1.4	0.12	0.00	0.08	0.6	0.04	0.4	8.1	1224	301	0.35	51	5	4.30
1	7	IWS	500	1	0.1	1.5	0.14	0.00	0.10	0.7	0.00	0.7	7.0	1404	355	0.40	64	7	4.43
1	7	IWS	500	2	0.2	1.5	0.12	0.00	0.10	0.7	0.00	0.6	7.2	1444	353	0.40	69	7	3.04

APPENDIX TABLE J: CONCENTRATION OF SELECTED ELEMENTS IN DIFFERENT CHEMICAL FORMS, AND IN CORN TISSUE GROWN IN A SUSPENSION OF CHICAGO REFERENCE SLUDGE:DRUMMER SOIL MATERIAL.

EX	EN	SAMPLE	EL AV	REP	CU	ZN	CD	PB	CR	NI	AS	FE	MN	CA	MG	MO	SI	P	AL
												UG/G							
J	5	CCBN	50	1	16.6	147.9	6.35	6.21	8.95	2.8	5.34	152.8	125.1	3000	3550	3.34	713	3926	412.55
J	5	CCBN	50	2	22.3	138.1	5.12	4.20	9.25	2.2	12.09	155.1	128.5	2677	3458	2.33	129	3898	55.90
J	5	CCBN	250	1	15.6	111.5	6.15	1.10	7.67	1.2	17.87	87.4	119.1	2495	2965	2.04	921	2784	161.44
J	5	CCBN	250	2	12.0	85.5	7.12	1.45	7.80	2.1	6.82	81.5	126.4	2511	2910	1.72	554	2685	61.56
J	5	CCBN	500	1	35.5	195.6	11.39	4.20	8.10	0.4	4.89	134.0	253.3	3673	5085	2.96	161	4553	54.04
J	5	CCBN	500	2	38.1	210.8	11.77	5.40	8.15	7.6	7.24	161.2	268.3	3774	5190	3.42	641	4603	176.80
J	5	DIPA	50	1	3.2	59.1	2.57	19.03	17.64	6.6	4.54	737.8	11.7	415	110	0.03	75	217	478.51
J	5	DIPA	50	2	4.8	63.2	2.16	16.92	16.92	5.9	4.83	669.6	10.9	303	100	0.05	123	191	258.06
J	5	DIPA	250	1	19.3	47.3	3.12	24.58	17.56	6.4	4.19	526.8	17.3	113	43	0.05	74	246	254.67
J	5	DIPA	250	2	20.0	44.2	3.19	24.61	17.08	6.4	4.13	499.7	16.6	120	37	0.49	122	217	241.06
J	5	DIPA	500	1	21.3	46.8	3.05	23.65	20.47	7.0	5.30	530.4	19.2	63	53	0.73	190	249	284.69
J	5	DIPA	500	2	23.9	50.8	3.13	24.10	21.18	7.5	5.24	572.9	18.1	83	39	0.04	248	274	324.96
J	5	EXCH	50	1	0.0	116.0	6.89	1.85	0.27	10.4	0.00	803.9	67.6	3025	462	0.00	31	87	0.00
J	5	EXCH	50	2	0.0	125.9	7.65	4.42	0.30	11.6	0.00	890.4	74.7	3310	508	0.00	34	96	11.07
J	5	EXCH	250	1	3.3	117.1	7.60	0.54	0.22	9.0	0.00	1.6	43.6	3640	740	0.00	93	31	10.60
J	5	EXCH	250	2	3.0	114.0	7.39	0.60	0.20	8.8	0.00	1.0	41.8	3457	664	0.00	22	28	0.38
J	5	EXCH	500	1	3.6	106.3	7.17	1.22	0.26	8.6	0.00	1.3	42.2	3479	643	0.00	37	27	0.00
J	5	EXCH	500	2	3.5	116.1	7.78	0.63	0.25	9.0	0.00	1.1	46.5	3720	749	0.00	60	29	0.00
J	5	H2O2	50	1	11.1	10.1	0.78	9.66	13.40	2.0	10.43	998.5	6.9	445	276	0.78	5	54	841.50
J	5	H2O2	50	2	12.7	11.9	0.87	10.70	15.53	2.3	11.56	1085.5	7.5	440	281	0.86	15	66	940.50
J	5	H2O2	250	1	3.2	11.8	0.72	9.51	15.80	2.2	10.74	1247.0	8.8	334	217	0.82	7	63	859.60
J	5	H2O2	250	2	3.2	12.3	0.69	9.82	16.65	2.3	10.95	1240.0	8.8	305	212	0.87	18	65	864.50
J	5	H2O2	500	1	30.1	120.7	7.14	94.50	153.80	22.0	98.50	11420	88.0	3325	2080	7.83	63	653	7780.00
J	5	H2O2	500	2	4.8	11.5	0.63	9.31	14.94	2.2	10.66	1214.5	8.9	335	229	0.82	16	60	850.60
J	5	OXAL	50	1	4.0	221.6	2.40	10.96	106.18	31.3	3.50	3352.4	56.4	46	407	2.42	23	1317	1639.32
J	5	OXAL	50	2	2.6	218.5	2.40	11.69	102.01	30.0	3.38	3298.9	53.2	81	396	2.35	105	1298	1595.14
J	5	OXAL	250	1	102.5	228.2	3.40	19.64	115.21	34.9	2.32	2322.1	70.4	55	240	2.24	115	1593	1575.77
J	5	OXAL	250	2	104.5	230.6	3.66	21.69	115.08	33.2	2.31	2149.4	69.7	75	252	2.20	44	1524	1561.14
J	5	OXAL	500	1	81.2	242.6	2.89	10.08	64.13	29.5	1.44	1122.0	55.9	560	415	0.97	23	274	481.43
J	5	OXAL	500	2	69.9	157.1	4.52	10.70	63.05	25.0	0.79	1028.3	46.6	19	162	0.87	58	171	448.29
J	5	TWS	50	1	0.4	33.7	1.54	0.84	0.31	6.5	1.66	592.5	56.5	2865	537	0.17	248	110	4.92
J	5	TWS	50	2	0.3	35.2	1.64	0.22	0.32	6.9	1.19	686.3	58.8	2991	615	0.10	148	107	13.47
J	5	TWS	250	1	0.5	41.8	2.25	0.00	0.28	5.0	0.00	1.3	39.4	3579	691	0.05	115	12	10.70
J	5	TWS	250	2	0.6	43.0	2.30	0.13	0.27	5.1	0.30	1.3	39.9	3962	955	0.16	68	14	5.46
J	5	TWS	500	1	0.5	48.8	2.35	0.05	0.30	5.6	0.00	1.5	42.0	3957	696	0.04	203	18	13.65
J	5	TWS	500	2	0.6	34.5	1.81	0.00	0.26	4.3	0.00	1.2	36.4	3618	669	0.05	187	11	9.04

APPENDIX TABLE K: CONCENTRATION OF SELECTED ELEMENTS IN DIFFERENT CHEMICAL FORMS, AND IN CORN TISSUE GROWN IN A SUSPENSION OF CHICAGO REFERENCE SLUDGE:CRUMMER SOIL MATERIAL.

EX	EH	SAMPLE	EE MV	REP	CU	ZN	CD	PB	CR	NI	AS	FE	MN	CA	MG	MO	SI	P	AL
												UG/G							
K	.	CELV	.	1	12.9	24.9	0.08	42.22	10.14	1.0	13.41	236.0	65.6	1983	86	0.28	198	2253	141.88
K	.	CELV	.	2	10.5	23.1	0.08	41.50	9.72	0.8	12.90	281.7	80.5	1883	81	0.41	419	2124	261.53
K	6	CCHA	-150	1	13.0	79.3	0.30	3.70	7.44	7.5	3.85	279.1	207.8	5000	208	1.31	306	4447	43.46
K	6	CCHA	-150	2	13.4	90.3	0.31	5.83	7.79	4.8	7.54	281.0	209.6	4596	207	1.47	567	4858	174.55
K	6	CCHN	150	1	16.5	156.6	0.88	4.19	8.16	4.7	8.48	267.1	235.1	5525	239	1.44	620	4835	207.74
K	6	CCHA	150	2	17.7	216.9	0.76	3.11	7.50	4.9	11.95	274.5	201.0	5358	201	1.18	358	5045	70.97
K	6	CCHN	250	1	19.3	241.0	8.37	6.76	6.16	6.8	14.24	75.5	154.3	6690	194	2.02	843	5250	244.10
K	6	CCHA	500	1	29.8	349.0	11.61	6.89	6.78	5.0	6.10	108.3	266.8	6155	267	2.00	456	6735	155.50
K	6	CCHA	500	2	33.9	576.5	11.58	9.47	7.96	4.6	8.63	103.8	256.4	5594	256	2.04	734	6625	279.24
K	6	EIPA	-150	1	4.7	62.9	3.04	17.52	15.19	7.3	3.50	623.7	21.8	125	116	0.47	190	179	212.11
K	6	EIPA	-150	2	3.5	71.4	3.47	22.49	18.05	8.3	5.02	768.0	25.5	126	126	0.62	172	230	444.62
K	6	EIPA	150	1	13.3	86.8	3.39	16.77	16.63	7.8	4.02	646.2	24.9	454	115	0.44	151	206	234.52
K	6	EIPA	150	2	16.8	68.9	3.23	18.51	16.28	7.4	4.23	519.2	21.9	131	117	.	464	183	252.75
K	6	EIPA	250	1	25.8	93.1	4.80	26.06	19.83	10.1	4.67	557.4	32.4	301	149	0.46	157	301	263.89
K	6	EIPA	250	2	21.3	76.0	3.80	20.29	19.67	9.1	4.66	552.6	29.2	104	141	0.49	490	455	265.41
K	6	EIPA	500	1	19.9	57.6	2.99	15.47	16.38	7.0	3.77	452.7	23.3	88	125	0.41	138	204	227.51
K	6	EIPA	500	2	20.9	61.5	3.34	16.26	18.35	8.0	4.39	500.2	26.2	77	140	0.49	248	233	281.34
K	6	EXCH	-150	1	0.2	14.6	0.05	0.00	0.15	1.3	0.00	1.0	11.8	3418	542	0.01	19	37	6.69
K	6	EXCH	-150	2	0.0	15.2	0.00	0.00	0.14	1.3	0.00	0.9	11.9	3447	540	0.00	4	39	2.98
K	6	EXCH	150	1	1.3	20.6	2.75	0.00	0.14	1.7	0.00	1.1	12.2	3693	550	0.00	3	24	4.80
K	6	EXCH	150	2	4.1	23.0	3.19	0.00	0.16	2.3	0.00	2.7	13.0	3867	570	0.00	2	25	5.41
K	6	EXCH	250	1	2.5	23.9	2.79	0.00	0.14	1.9	0.00	1.8	14.4	3558	532	0.00	5	21	3.96
K	6	EXCH	250	2	2.8	21.3	3.08	0.00	0.18	2.1	0.00	3.3	13.3	3875	567	0.04	14	23	6.41
K	6	EXCH	500	1	3.1	19.2	2.63	0.00	0.16	1.8	0.00	1.0	5.7	3405	507	0.02	6	18	3.55
K	6	EXCH	500	2	3.0	19.9	2.68	0.00	0.14	1.9	0.00	0.8	5.9	3490	510	0.02	3	17	3.25
K	6	HZO2	-150	1	140.00	143.6	16.54	120.60	175.25	25.5	110	11240	51.4	5745	2682	8.08	51	635	8835.00
K	6	HZO2	-150	4	132.4	120.7	15.15	110.10	155.75	23.2	111.6	10810	81.0	5575	2661	8.45	48	544	8895.00
K	6	HZO2	150	1	83.1	131.5	12.44	113.65	153.90	23.8	112.2	12180	68.8	5745	2701	8.43	47	615	8580.00
K	6	HZO2	150	2	46.3	129.1	12.57	114.50	148.45	24.0	111.6	14295	51.4	5770	2646	8.40	53	577	8870.00
K	6	HZO2	250	1	54.1	192.5	12.40	118.40	182.40	30.3	130.8	14580	116.8	6010	2852	9.85	76	770	10455
K	6	HZO2	250	2	49.7	171.2	12.35	111.95	158.25	26.9	108.1	12245	102.5	5865	2681	8.44	245	704	8565.00
K	6	HZO2	500	1	31.0	172.6	12.96	114.80	157.80	26.3	106.3	12365	55.0	5825	2688	8.24	122	639	8480.00
K	6	HZO2	500	2	34.2	193.3	13.51	126.65	175.90	29.0	122.2	13790	109.9	5885	2818	9.29	206	706	9775.00
K	6	CIAL	-150	1	4.9	337.0	3.37	14.32	125.67	45.0	6.41	1136.2	135.5	106	643	2.48	90	1004	1742.37
K	6	CIAL	-150	2	9.4	465.3	2.53	9.35	91.61	35.9	3.08	2298.3	166.8	174	571	1.65	54	761	1154.70
K	6	CIAL	150	1	49.8	327.8	3.63	13.18	128.79	46.1	4.42	2902.5	126.5	58	597	2.34	141	1728	1734.83
K	6	CIAL	150	2	42.8	330.5	3.77	14.23	133.79	47.9	4.06	2660.7	144.9	30	610	2.34	177	1863	1804.31
K	6	CIAL	250	1	59.5	204.2	2.45	7.85	78.22	28.4	1.82	1386.6	82.3	58	461	0.91	64	493	574.75
K	6	CIAL	250	2	64.2	244.4	2.54	7.76	86.49	32.5	1.85	1188.6	92.9	205	517	1.11	71	387	828.89
K	6	CIAL	500	1	118.7	312.7	2.78	12.85	128.79	46.9	3.13	2077.5	133.9	30	634	2.23	135	1556	1745.60
K	6	CIAL	500	2	81.7	225.3	2.70	7.52	78.44	33.4	1.38	1319.5	93.4	19	509	1.00	45	481	620.31
K	6	IWS	-150	1	0.3	0.4	0.05	0.07	0.25	1.0	0.06	4.3	0.9	450	74	0.74	43	37	18.13
K	6	IWS	-150	2	0.5	1.3	0.10	0.02	0.46	1.1	0.34	8.0	1.1	324	75	0.84	46	44	6.49
K	6	IWS	150	1	0.0	0.7	0.07	0.00	0.16	0.9	0.21	5.0	0.8	308	73	0.78	33	22	3.09
K	6	IWS	150	2	0.3	0.5	0.08	0.14	0.18	0.9	0.45	4.9	0.9	318	77	0.83	31	42	4.78
K	6	IWS	250	1	0.0	0.0	0.06	0.00	0.11	0.6	0.11	3.3	1.0	375	99	0.75	45	15	5.58
K	6	IWS	250	2	0.4	0.5	0.06	0.00	0.10	0.7	0.00	3.5	1.1	466	108	0.80	47	16	10.50
K	6	IWS	500	1	0.4	0.5	0.06	0.00	0.15	0.6	0.15	2.8	0.5	319	80	0.75	36	12	4.14
K	6	IWS	500	2	1.0	0.7	0.07	0.00	0.16	0.6	0.06	3.5	0.5	341	86	0.76	36	13	5.29

APPENDIX TABLE 1: CONCENTRATION OF SELECTED ELEMENTS IN DIFFERENT CHEMICAL FORMS, AND IN RACE TISSUE GROWN IN A SUSPENSION OF CHICAGO REFERENCE SLUDGE:LOAMING SOIL MATERIAL.

BX	IN	SAMPLE	FI AV	REP	CU	ZN	CD	PB	CR	NI	AS	FE	MN	CA	MG	NO	SI	P	AL
												UG/G							
1	.	BLNK	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
1	.	BLNK	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
1	.	CONT	.	1	42.7	32.2	4.89	4.80	24.12	5.0	6.91	134.5	869.1	2333	489	4.28	2817	9466	478.10
1	.	CONT	.	2	40.7	73.6	4.28	15.64	20.03	4.8	0.00	231.6	533.3	2750	533	2.94	431	10155	21.15
1	7	EIPA	150	1	10.4	73.8	1.09	5.29	22.07	6.4	2.72	430.5	83.2	27	126	0.36	204	107	180.67
1	7	EIPA	150	2	10.6	80.6	1.11	5.66	23.24	6.7	2.80	413.1	85.3	68	131	0.33	187	105	176.12
1	7	EIPA	250	1	11.8	71.4	0.97	6.65	21.53	6.8	3.12	445.3	84.6	49	133	0.37	92	98	167.31
1	7	EIPA	250	2	12.7	71.5	0.70	5.73	21.60	6.5	3.05	473.3	83.7	41	130	0.32	174	109	184.02
1	7	EIPA	500	1	7.4	66.0	0.69	5.67	15.63	5.2	2.31	340.5	53.1	92	111	0.30	30	93	114.96
1	7	EIPA	500	2	7.2	56.2	0.68	6.39	15.82	5.3	2.77	302.2	53.6	43	107	0.26	171	85	146.25
1	7	EIPA	1000	1	14.7	81.4	0.97	7.19	27.90	8.1	3.74	493.7	110.8	35	142	0.41	195	171	214.45
1	7	EIPA	1000	2	11.7	72.9	0.93	7.34	24.66	7.3	3.21	410.0	97.2	19	128	0.67	63	149	160.36
1	7	EXCH	100	1	2.0	30.9	3.81	0.62	0.12	2.6	0.83	19.2	269.5	1119	102	0.04	168	11	39.43
1	7	EXCH	100	2	1.6	32.7	4.01	0.46	0.10	2.7	0.56	17.1	241.2	1168	106	0.02	53	11	4.92
1	7	EXCH	200	1	2.8	30.8	4.93	0.27	0.10	2.8	0.40	14.0	227.7	1172	109	0.02	118	16	27.16
1	7	EXCH	200	2	3.0	39.7	4.85	0.51	0.11	2.8	0.56	9.3	240.6	1191	107	0.08	117	11	27.51
1	7	EXCH	500	1	4.3	45.3	3.66	0.49	0.17	2.3	0.81	2.5	140.6	1078	112	0.10	156	11	34.97
1	7	EXCH	500	2	1.6	32.0	4.25	0.41	0.16	2.4	0.27	3.1	131.0	1211	121	0.07	17	12	4.80
1	7	EXCH	1000	1	3.3	29.4	3.91	0.22	0.30	2.2	0.57	1.2	3.0	1457	163	0.08	145	13	31.66
1	7	EXCH	1000	2	3.0	24.1	3.18	0.44	0.24	2.0	0.67	1.0	2.2	1361	191	0.11	142	12	30.90
1	7	B202	100	1	126.3	72.4	15.95	138.95	110.25	14.7	55.50	3168.5	66.3	3350	1279	3.97	353	371	4698.00
1	7	B202	100	2	115.8	74.7	15.13	130.25	108.25	13.4	54.25	3289.0	63.5	3179	1212	3.73	312	354	4467.50
1	7	B202	200	1	58.1	68.6	14.60	131.90	95.65	14.9	59.45	3772.0	92.4	3555	1605	4.22	254	391	4944.00
1	7	B202	200	2	49.9	66.2	12.48	120.50	87.05	13.0	48.45	3170.0	81.8	3136	1410	3.48	433	317	3998.00
1	7	B202	500	1	35.0	73.2	12.05	116.25	80.45	13.4	53.05	4127.6	89.2	3066	1223	4.00	1003	360	4346.50
1	7	B202	500	2	34.8	82.4	11.72	109.10	76.55	12.9	52.55	4157.6	86.9	3132	1237	3.88	457	368	4260.00
1	7	B202	1000	1	27.8	75.1	14.76	120.40	95.75	14.1	53.85	4178.5	77.4	3143	1148	4.16	689	354	4429.00
1	7	B202	1000	2	33.6	87.2	16.47	131.45	108.70	14.9	59.15	4614.0	87.2	3459	1170	4.44	899	434	4895.00
1	7	CRAL	100	1	19.4	375.8	1.32	8.28	182.83	50.1	22.31	4778.1	324.3	100	458	4.47	450	1085	1485.36
1	7	CRAL	100	2	26.2	338.1	1.19	6.83	160.81	44.0	19.06	4097.5	288.4	169	406	2.08	158	1526	1267.13
1	7	CRAL	50	1	70.5	284.9	0.73	9.96	159.28	35.4	19.41	4052.6	256.4	236	406	2.17	212	1504	1291.22
1	7	CRAL	50	2	74.6	372.9	0.88	7.81	166.50	44.1	20.10	4212.5	263.6	465	432	2.43	230	1572	1337.70
1	7	CRAL	250	1	80.4	285.5	0.93	5.90	124.36	38.7	13.97	2863.4	420.2	167	407	1.79	214	1211	1004.57
1	7	CRAL	250	2	75.1	264.8	0.88	5.64	118.07	36.4	13.27	2762.8	399.2	39	375	1.88	164	1176	923.45
1	7	CRAL	500	1	111.6	353.4	1.14	7.01	165.13	46.3	18.36	3365.2	686.0	150	433	2.31	193	1585	1195.12
1	7	CRAL	500	2	111.7	375.4	1.10	7.34	164.46	46.5	16.19	3247.3	644.8	323	441	2.47	142	1531	1181.96
1	7	BICE	50	1	51.7	86.3	4.08	3.16	8.72	7.8	11.75	131.6	824.1	2937	822	3.72	729	8020	193.66
1	7	BICE	50	2	63.7	76.3	1.43	0.23	7.22	6.9	19.95	129.6	751.0	2886	751	3.28	425	5365	9.05
1	7	BICE	50	1	47.8	63.5	2.85	2.68	7.07	6.8	9.70	102.3	522.5	2179	942	3.13	353	5340	43.11
1	7	BICE	50	2	44.6	67.0	2.98	1.44	8.15	6.6	6.40	108.4	542.0	2276	942	3.05	368	5560	41.03
1	7	BICE	250	1	96.2	143.1	27.56	3.89	12.69	8.9	14.20	96.1	852.0	3372	852	3.96	1214	7091	287.00
1	7	BICE	250	2	74.6	131.1	27.39	4.98	11.97	8.7	6.88	87.9	833.8	3019	838	3.72	133	7108	11.03
1	7	BICE	500	1	49.8	177.4	54.58	1.74	7.56	7.8	3.63	65.5	281.5	2866	242	4.42	253	2498	39.86
1	7	BICE	500	2	29.7	166.0	53.17	1.15	7.85	7.2	12.09	65.4	285.3	2816	245	4.57	91	5435	22.60
1	7	IWS	100	1	1.5	4.2	0.23	0.01	0.14	1.5	0.23	28.3	135.0	569	152	0.34	96	6	0.23
1	7	IWS	100	2	0.6	3.4	0.21	0.07	0.12	1.4	0.16	27.0	127.9	520	163	0.31	99	6	0.18
1	7	IWS	50	1	0.1	4.1	0.33	0.05	0.06	1.3	0.06	4.2	181.3	1001	154	0.19	94	4	0.00
1	7	IWS	50	2	1.0	4.2	0.36	0.00	0.11	1.4	0.23	3.6	185.2	1026	156	0.24	98	5	0.23
1	7	IWS	250	1	0.4	1.7	0.13	0.00	0.08	0.7	0.00	1.4	89.9	781	134	0.13	88	3	0.00
1	7	IWS	250	2	0.1	1.5	0.12	0.02	0.06	0.8	0.00	1.0	89.9	759	126	0.17	96	4	0.00
1	7	IWS	500	1	0.4	0.7	0.02	0.00	0.18	0.5	0.00	0.4	0.0	624	121	0.07	76	4	0.00
1	7	IWS	500	2	0.7	1.0	0.03	0.00	0.17	0.5	0.00	0.4	0.1	635	112	0.09	76	4	0.00

APPENDIX TABLE N: CONCENTRATION OF SELECTED ELEMENTS IN DIFFERENT CHEMICAL FORMS, AND IN RICE TISSUE GROWN IN A SUSPENSION OF CHICAGO REFERENCE SLUDGE:LORING SOIL MATERIAL.

EX	IN	SAMPLE	EH MV	REP	CU	ZN	CD	PB	CR	NI	AS	FE	MN	LA	MG	MO	SI	P	AL
												UG/G							
A	.	BLNK	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	0	.
A	.	BLNK	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	0	.
A	.	RICE	.	1	42.7	52.2	3.89	4.80	24.12	5.0	6.91	134.5	469.1	2.33	489	4.28	2417	58	478.10
A	.	RICE	.	2	30.7	75.5	3.28	15.62	20.03	4.8	0.00	231.6	533.4	2750	533	2.94	431	39	1.15
A	8	DIPA	-150	1	8.9	82.2	0.89	6.28	24.82	7.7	2.54	568.2	68.6	36	152	0.54	91	15	177.29
A	8	DIPA	-150	2	9.2	82.4	1.04	6.06	25.41	8.2	2.31	605.7	76.3	26	155	0.46	59	16	179.20
A	8	DIPA	50	1	9.7	74.6	0.92	5.61	21.97	6.8	1.92	480.2	67.0	24	127	0.41	70	13	149.13
A	8	DIPA	50	2	10.5	111.3	0.90	6.27	39.18	11.5	3.74	818.6	111.2	36	181	0.65	117	28	275.62
A	8	DIPA	250	1	10.6	75.8	0.95	5.77	23.32	7.1	1.75	434.2	82.7	17	136	0.36	56	16	148.25
A	8	DIPA	250	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A	8	DIPA	500	1	11.9	71.5	0.99	5.68	23.08	6.8	1.64	430.8	58.8	14	119	0.35	61	17	147.60
A	8	DIPA	500	2	9.8	62.1	0.79	5.31	19.34	5.8	1.47	380.7	64.8	12	125	0.31	59	15	127.18
A	8	EXCH	-150	1	0.1	16.9	3.50	0.00	0.10	1.4	0.25	2.9	201.2	1398	164	0.04	32	3	7.52
A	8	EXCH	-150	2	0.1	17.9	3.68	0.00	0.11	1.4	0.28	4.7	210.5	1470	172	0.05	20	3	6.66
A	8	EXCH	50	1	0.7	19.1	4.16	0.00	0.11	1.6	0.25	3.7	156.5	1618	183	0.03	3	3	2.19
A	8	EXCH	50	2	0.5	17.7	3.81	0.12	0.11	1.3	0.24	2.7	182.6	1502	172	0.05	34	3	8.84
A	8	EXCH	250	1	1.1	15.8	3.89	0.00	0.12	1.6	0.77	3.4	102.0	1557	178	0.07	93	2	48.51
A	8	EXCH	250	2	1.1	16.8	3.25	0.00	0.08	1.3	0.54	3.9	68.1	1356	158	0.01	80	2	19.54
A	8	EXCH	500	1	1.1	16.3	3.10	0.00	0.17	1.2	0.61	3.5	3.9	1627	193	0.03	111	2	25.77
A	8	EXCH	500	2	1.8	17.9	3.07	0.00	0.14	1.4	0.36	3.3	3.7	1616	193	0.02	43	3	6.19
A	8	B2G2	-150	1	92.9	68.3	14.82	117.30	91.10	12.6	43.86	2887.0	105.4	3361	1172	3.10	538	8	3681.50
A	8	B2G2	-150	2	61.2	43.6	5.79	61.85	64.30	8.3	24.04	2040.5	68.3	2185	742	2.41	407	4	2826.50
A	8	B2G2	50	1	66.9	66.7	14.50	123.00	92.45	13.3	48.75	3557.0	99.0	3413	1237	3.62	503	7	3953.50
A	8	B2G2	50	2	77.0	84.9	15.32	128.05	101.80	15.5	57.45	4170.5	111.8	3369	1290	4.17	237	8	4755.00
A	8	B2G2	250	1	93.7	91.9	17.31	140.70	115.95	16.2	56.86	4534.5	110.9	3594	1241	4.30	651	8	4671.50
A	8	B2G2	250	2	93.3	102.7	19.11	154.65	127.20	18.6	64.60	5180.0	129.7	5129	1898	4.80	951	10	5340.50
A	8	B2G2	500	1	23.9	80.5	15.12	115.60	99.15	13.4	52.40	4153.0	77.1	3327	1156	3.38	454	7	4186.50
A	8	B2G2	500	2	25.4	98.8	19.43	147.75	122.35	16.5	62.65	5160.0	97.5	4464	1534	4.54	238	16	5175.00
A	8	CHAL	-150	1	33.3	350.8	0.97	8.55	164.92	46.9	18.41	4153.7	410.7	46	511	2.21	249	170	1426.09
A	8	CHAL	-150	2	27.2	322.3	1.99	7.63	150.27	42.9	16.66	3969.3	363.4	38	455	2.01	173	166	1165.77
A	8	CHAL	50	1	57.3	220.3	0.82	7.78	167.83	26.0	16.51	2983.5	225.5	162	372	1.88	194	161	1259.82
A	8	CHAL	50	2	56.8	328.5	0.95	7.75	166.50	45.5	16.83	3385.2	404.0	313	448	2.01	132	164	1230.00
A	8	CHAL	250	1	93.4	334.6	0.93	7.40	153.38	43.3	13.09	2889.7	493.8	172	445	1.82	204	134	1120.49
A	8	CHAL	250	2	93.1	325.4	0.85	7.22	153.45	43.0	13.92	3033.8	458.4	76	463	1.86	157	174	1101.25
A	8	CHAL	500	1	112.4	327.1	0.90	7.04	158.64	46.1	14.48	2454.5	648.6	68	515	1.77	26	120	1151.94
A	8	CHAL	500	2	98.9	325.0	0.88	6.91	144.47	43.0	14.34	2777.2	605.6	125	477	1.61	80	146	1048.56
A	8	RICE	-150	1	18.7	28.8	0.56	0.74	11.60	3.8	0.00	110.9	312.6	1849	313	3.74	240	65	26.24
A	8	RICE	-150	2	21.6	29.8	0.43	2.74	12.95	4.2	5.15	124.5	315.0	2005	315	4.47	981	61	231.99
A	8	RICE	50	1	39.6	26.8	1.59	1.80	7.66	2.8	1.33	107.2	274.5	1840	274	3.71	217	83	21.83
A	8	RICE	50	2	34.7	25.2	1.41	0.00	7.06	2.4	6.77	100.7	226.6	1526	247	3.21	292	84	30.53
A	8	RICE	250	1	21.6	62.3	2.01	4.58	10.26	7.0	6.33	106.7	477.9	2190	478	4.54	930	52	248.39
A	8	RICE	250	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
A	8	RICE	500	1	25.0	87.0	2.58	2.65	8.97	6.1	9.97	70.5	156.2	1989	196	4.17	853	66	211.18
A	8	RICE	500	2	22.3	83.8	2.62	4.43	9.35	5.5	3.08	75.9	168.4	1948	188	4.30	746	65	170.27
A	8	TBS	-150	1	0.8	1.2	0.04	0.18	0.43	1.0	0.06	17.9	13.6	260	50	0.56	.	3	0.66
A	8	TBS	-150	2	1.1	1.1	0.05	0.01	0.41	1.0	0.00	17.4	13.1	260	51	0.60	.	3	0.00
A	8	TBS	50	1	2.7	1.7	0.06	0.32	0.47	0.9	0.36	26.4	10.2	231	44	0.57	.	3	0.36
A	8	TBS	50	2	1.8	1.6	0.05	0.20	0.43	0.9	0.34	24.5	10.0	230	45	0.58	.	3	0.34
A	8	TBS	250	1	1.4	1.2	0.05	0.09	0.45	0.7	0.00	23.3	6.0	267	45	0.58	.	3	0.00
A	8	TBS	250	2	1.7	1.2	0.04	0.41	0.39	0.7	0.27	18.5	5.5	201	37	0.53	.	3	0.27
A	8	TBS	500	1	1.2	0.9	0.01	0.02	0.53	0.6	0.02	10.4	2.7	166	30	0.50	.	3	0.02
A	8	TBS	500	2	1.5	0.9	0.04	0.15	0.54	0.6	0.14	12.6	2.9	153	29	0.48	.	3	0.14

APPENDIX TABLE N

CONCENTRATION OF SELECTED ELEMENTS IN CORN AND SOYBEANS GROWN IN A 5 PERCENT MIXTURE OF AEROBICALLY AND ANAEROBICALLY DIGESTED BATON ROUGE SLUDGE AND DRUMMER SOIL MATERIAL

PLANT	BATCH	TREATMENT	REP	CU	ZN	CD	PB	CR	NI	AS	FE	MN	CA	MG	MO	SE	P	AL
				←µUG/G→														
CORN	0	CONT	1	20.0	161	0.00	0.66	6.25	1.31	0.00	137	94	9798	8317	0.91	1.0	7954	42
CORN	0	CONT	2	13.8	154	0.11	0.00	4.78	1.05	0.00	145	84	7870	6726	1.16	1.2	6682	59
CORN	0	CONT	3	14.8	154	0.12	0.00	5.16	1.84	0.00	170	80	8250	6984	1.21	2.5	6352	67
CORN	0	CONT	4	12.4	129	0.12	0.15	3.84	1.48	0.00	115	55	7518	6374	1.57	1.9	5630	36
CORN	0	CONT	5	12.4	136	0.13	0.00	3.76	0.88	0.00	137	66	7860	7237	1.43	0.3	6342	40
CORN	S	AEBC	1	16.1	143	0.45	1.66	6.68	1.26	0.40	108	65	6627	6657	3.71	18.9	8675	35
CORN	S	AEBC	2	17.1	128	0.35	1.11	6.56	15.23	0.56	112	70	7348	7227	2.99	21.8	9079	54
CORN	S	AEBC	3	12.4	118	0.27	0.62	4.84	0.81	0.08	92	66	6863	6432	4.80	3.3	7863	34
CORN	S	AEBC	4	14.3	142	0.30	0.10	5.58	1.05	0.25	110	81	7112	6604	3.59	19.1	8396	67
CORN	S	AEBC	5	13.3	147	0.65	0.56	7.16	1.60	0.59	119	69	7115	6314	2.30	10.8	8141	44
CORN	S	ANAE	1	23.2	153	0.48	0.96	6.27	1.05	0.10	112	55	7816	6466	2.16	13.7	8333	25
CORN	S	ANAE	2	24.1	192	0.75	1.31	10.60	1.09	0.82	143	132	9545	7459	1.70	23.4	8315	51
CORN	S	ANAE	3	17.0	114	0.29	1.13	5.72	1.42	0.38	84	71	7779	7133	1.71	12.7	7779	29
CORN	S	ANAE	4	16.8	151	0.27	3.06	5.11	1.16	0.19	108	71	6803	6316	1.93	7.7	6687	28
CORN	S	ANAE	5	23.0	160	0.57	3.67	12.93	2.30	1.15	115	67	8736	6667	1.72	31.1	7931	42
SOYB	0	CONT	1	11.5	69	0.14	0.00	0.79	7.86	0.00	107	51	11506	3491	2.91	5.5	5541	55
SOYB	0	CONT	2	11.5	59	0.27	0.00	0.92	3.21	0.00	119	54	10467	5272	2.29	3.1	4032	76
SOYB	0	CONT	3	13.0	78	0.16	0.00	0.54	6.27	0.03	142	45	10834	3408	2.23	2.1	5274	86
SOYB	0	CONT	4	11.3	66	0.42	0.38	0.47	7.15	0.03	88	77	10111	5189	8.98	3.3	5022	39
SOYB	0	CONT	5	14.4	63	0.07	0.00	0.50	5.46	0.00	78	56	10467	4893	3.28	3.4	5455	39
SOYB	S	AEBC	1	13.7	78	0.24	0.28	0.55	4.03	0.08	74	64	8554	4462	5.18	4.3	4818	30
SOYB	S	AEBC	2	12.0	67	0.14	0.60	0.45	4.06	0.00	58	50	7300	4159	5.45	1.7	5339	46
SOYB	S	AEBC	3	13.7	82	0.40	0.00	0.57	6.64	0.07	170	62	8091	4306	5.11	5.2	6248	105
SOYB	S	AEBC	4	11.0	63	0.07	0.00	0.59	5.51	0.65	194	50	7725	4420	4.95	12.4	4576	133
SOYB	S	AEBC	5	13.3	91	0.09	0.00	0.61	16.32	0.00	111	76	9445	4776	3.62	3.1	7218	57
SOYB	S	ANAE	1	15.0	76	0.60	0.00	0.61	5.68	0.00	110	61	8640	4836	14.81	6.3	5642	59
SOYB	S	ANAE	2	12.7	69	0.16	0.00	0.54	4.33	0.14	110	63	7564	4405	6.23	3.4	4878	55
SOYB	S	ANAE	3	13.8	74	0.24	0.00	0.42	5.39	0.12	90	66	7780	4422	5.72	11.4	5162	22
SOYB	S	ANAE	4	14.8	76	0.15	0.06	0.47	6.72	0.12	78	64	9110	4670	7.52	5.9	5448	25
SOYB	S	ANAE	5	14.1	82	0.13	0.00	0.76	6.45	0.00	85	55	9622	5018	8.19	11.8	6299	49